Harnessing America's
abundant natural resources
for clean power generation

Wind and Hydropower Technologies Program

Wind Energy
Multi Year Program Plan

For 2005-2010

November 2004

U.S. Department of Energy
Energy Efficiency
and Renewable Energy

Table of Contents

1.0 Introduction

The Wind Energy Program ("Wind Program"), managed by Office of Energy Efficiency and Renewable Energy of the United States Department of Energy, is a broad-based effort focused on increasing the viability of wind technology for use in the emerging energy marketplace. The Wind Program is one element of the Office of Wind and Hydropower Technologies Program.

1.1 Scope

This Multi Year Program Plan describes the Wind Program's support for research on wind turbines for utility and distributed applications. The Plan includes activities that target both technology development and institutional barrier reduction. Because wind systems can meet a wide range of needs in the marketplace, the Wind Program is sponsoring activities that target the needs of the wind research community, manufacturers, wind plant developers, and the energy-consuming public.

This Plan describes program research activities and milestones for a six fiscal year time horizon (2005-2010). In developing the Plan, the Wind Program assumes that funding levels will remain at about the FY 2004 levels until the latter part of the planning horizon, when activities will begin to taper off as goals for elements of the program are met and research activities conclude.

2.0 Background

2.1 Program History

The Federal government has been sponsoring wind systems research since 1972. The early program, at the National Science Foundation, was driven by the needs of electric utilities and by the potential of wind as a "fuel saver" during the oil crisis. This utility focus led to a program to develop large-scale wind turbines. Other elements of the early program included technical and market analysis, environmental impact assessment, innovative systems design, vertical axis wind turbine development, and rural applications. The program also provided design review and testing for small turbine manufacturers.

At that time, analysts believed that large turbines had a strong potential for economies of scale, that energy production would be increased by tapping the better resources accessible using taller towers, and that utilities would primarily be interested in larger-sized units. When the program began, the feasibility of using large wind turbines (defined as turbines rated at 100 kW or larger) for grid-tied generation had not been established. The Mod-0, installed in 1975, and its variant, the Mod-0A, a 100-kW turbine that was operated at four sites, proved the feasibility of large turbine technology and provided a test bed for further innovation. The first megawatt-scale wind turbine, the Mod-1 (1979-1980), generated annoying noise, leading to research into noise mitigation. Three Mod-2 turbines, rated at 2.5 MW each, were deployed from 1980-1986. These turbines demonstrated several design innovations, but also experienced loads and stresses that were far above those originally anticipated. The 3.2-MW Mod-5B, the largest and last turbine in the series, corrected the significant design shortcomings of the Mod-2 machines and passed its acceptance tests in 1988, but never achieved commercial acceptance, in part because of the unfavorable market conditions created by low oil prices. While these large turbine designs were never deployed commercially, this research identified the limitations of early design approaches and helped define the scope of subsequent research and development efforts.

Other notable program work in the late 1970s and early 1980s included: the development of a National Wind Atlas that is still in use today, in updated form; initiation of airfoil research that reduced sensitivity to fouling, which was a problem with blade designs using aircraft airfoils; and work on improved materials and structural designs that has developed into an extensive knowledge base used by today's designers. That early work also began to define the somewhat unexpected complexity of the wind inflow, and to identify ways to mitigate its negative effects on turbine reliability and lifetime.

Due to favorable development incentives and regulatory reforms, California became a hotbed of wind power development between 1981 and 1985. (Figure 1 provides a chronology of developments in the post-1980 era.) The turbines used in these early commercial installations were all much smaller than the systems developed by the DOE Large Turbine program. Industry developed these small systems to reduce risk in the absence of modeling and design tools. The incremental steps followed by the small turbine manufacturers al lowed extrapolation of lessons learned to machines of increasing size and sophistication, while taking advantage of available policy support. The initial California turbines came from U.S. companies, but within a year or two,

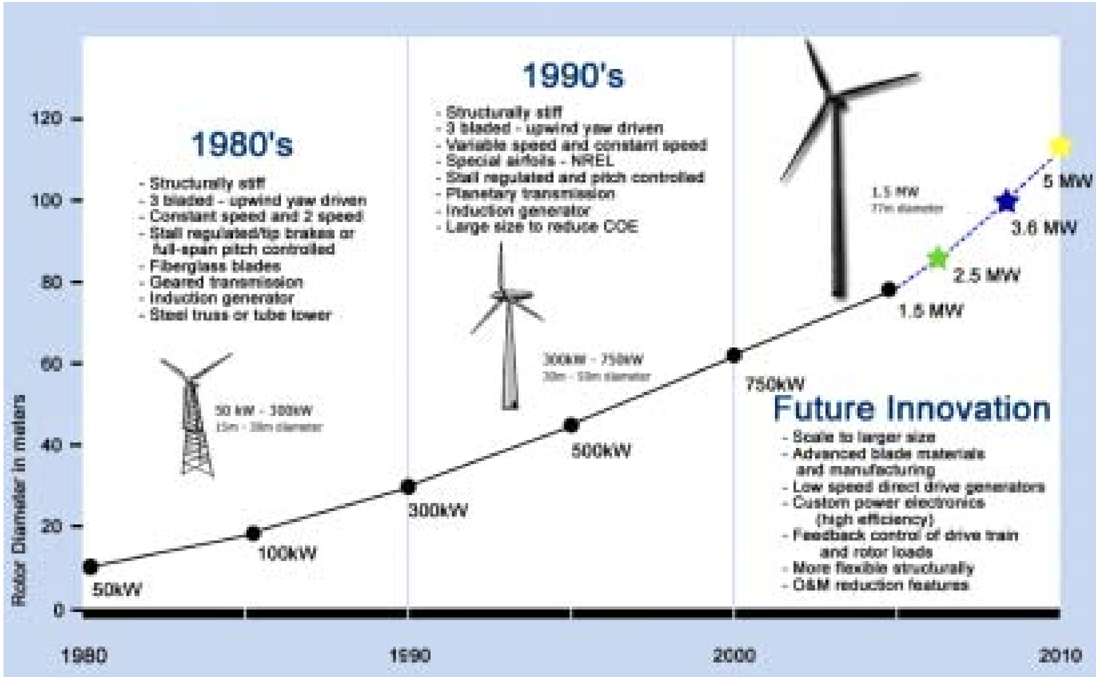


Figure 1. Wind Technology Developments Beginning in 1980

very sturdily designed Danish, Dutch, and other European turbines captured increasing market share. When new installations began dropping off in 1986, due to a decline in tax credits and California market incentives, many of the U.S. manufacturers went bankrupt.

In 1990, the program refocused its activities and developed a new strategy built around collaborative activities with utilities and industry. This new emphasis arose from the experience gained from earlier R&D activities, and from guidance of the National Energy Strategy (NES), which was developed in 1989 and 1990. An important element of that strategy was to help broaden wind's use beyond California. To that end, four objectives were adopted: 1) maintain present generation; 2) increase industry competitiveness; 3) upgrade the research base; and 4) develop advanced wind turbines.

The Advanced Wind Turbine (AWT) Program was initiated by the Department of Energy in 1990 to assist the U. S. industry in incorporating advanced technology into its wind turbine designs.

The first phase of the AWT Program, Conceptual Design Studies, which was completed in 1992, identified and evaluated improvements that were intended to make existing wind turbines more competitive over the following few years. It also explored more advanced configurations that would be competitive for bulk-electricity generation in later years at sites having moderate wind speeds. Study results indicated that these advanced configurations were capable of achieving substantial improvements in performance, reliability and cost of energy.

The second phase of the AWT Program, Near Term Product Development, continued for nearly four years. This effort involved the fabrication and testing of prototype turbines designed to produce electricity for $0.05/kWh or less at 5.8 m/s (13 mph) sites in the “near term”. These products were intended to bridge the gap between earlier technology and the "next-generation" of utility-grade turbines.

The third phase of the AWT Program, Next Generation Product Development, stimulated U. S. industry to explore new concepts and to apply cutting-edge technology to the development of prototype, utility-grade wind-turbine systems. The stated objective was to produce electricity for $0.025/kWh or less at 6.7 m/s (15 mph) sites. This third phase was managed as a two-part process. In the first part, the Innovative Subsystems Project, DOE supported industry in developing and testing of innovative components and subsystems. In the second part, the Next Generation Turbine Development Project (NGTD), DOE assisted industry in developing utility-grade, wind-turbine systems that would incorporate these, and other, innovations.

The NGTD began with three Concept Definition Studies, which were intended to develop reliable performance and cost estimates for the Subcontractor's proposed systems, along with a preliminary work plan, budget and schedule for the Prototype Development stage of the project. Beginning in 1997, two turbines were developed under this activity and one of these designs emerged as a very successful commercial product.

The industry-driven strategy that was implemented in the early 1990s laid the groundwork for today’s R&D program. It began a series of program-sponsored efforts to work closely with industry to develop wind turbines that are significantly more cost-competitive than their predecessors.

The remainder of this Plan details the focus and strategy of the Wind Program as it builds upon the important R&D successes of the 1990s.

2.2 Authority

The Wind Program operates under the following statutory authorizations:

- P.L. 94-163, Energy Policy and Conservation Act (EPCA) (1975)
- P.L. 94-385, Energy Conservation and Product Act (ECPA) (1976)
- P.L. 95-91, Department of Energy Organization Act (1977)
- P.L. 95-619, National Energy Conservation Policy Act (NECPA) (1978)
- P.L. 101-218, Renewable Energy and Energy Efficiency Technology Competitiveness Act of 1989
- P.L. 101-575, Solar, Wind, Waste and Geothermal Power Production Act of 1990
- P.L. 102-486, Energy Policy Act of 1992 (EPACT)

In addition, low wind speed technology development is recognized in the National Energy Policy (NEP) as an opportunity for significantly expanding wind energy use.

3.0 Program Goals, Planning and Evaluation

3.1 Vision of Wind Future

Wind energy will become a major source of energy for the nation, which has only begun to tap its vast wind resources. The wind community has set a target of 100 GW of wind electric capacity installed in the U.S. by 2020. At that level of utilization, wind will be displacing about 3 quads (quadrillion Btu) of primary energy per year, and 65 million metric tons of carbon equivalent per year. Extensive deployment of smaller wind systems, in distributed settings, is also part of industry's target. The Wind Program embraces this vision of the future potential for wind.

A number of non-technology factors have helped to bring the U.S. market to where it is today. Among these are the Federal Production Tax Credit, state-mandated renewable portfolio standards, and a growing market for consumer-purchased green power. The rapid improvement of wind technology, when added to the impetus provided by these market factors, will position wind to compete to become a significant source of energy for the future.

As the DOE wind energy program looks to the future, there appear to be three development paths that utility-scale wind technology may follow. Each of the three paths will have its own set of technology challenges and will encounter its own unique non-technology barriers. All three of these paths emanate from current technology, which is oriented toward producing bulk power from land-based wind farms.

Land-based Electricity Path – As the program looks to the future, it envisions that land-based systems will continue to grow in size, to the 2-5 MW range (Figure 2). This path is an important focus of the current DOE program and is expected to result in very cost-competitive turbine technology in the 2012 timeframe. The Program's efforts will also open up vast resources to wind development and will bring wind-generated electricity closer to major load centers. Turbine technology development efforts, such as are described in this plan, will help the technology to become cost-competitive. Ultimately, the primary barriers to the use of this technology will be those presented by system integration issues, including the capability and availability of the U.S. transmission system.

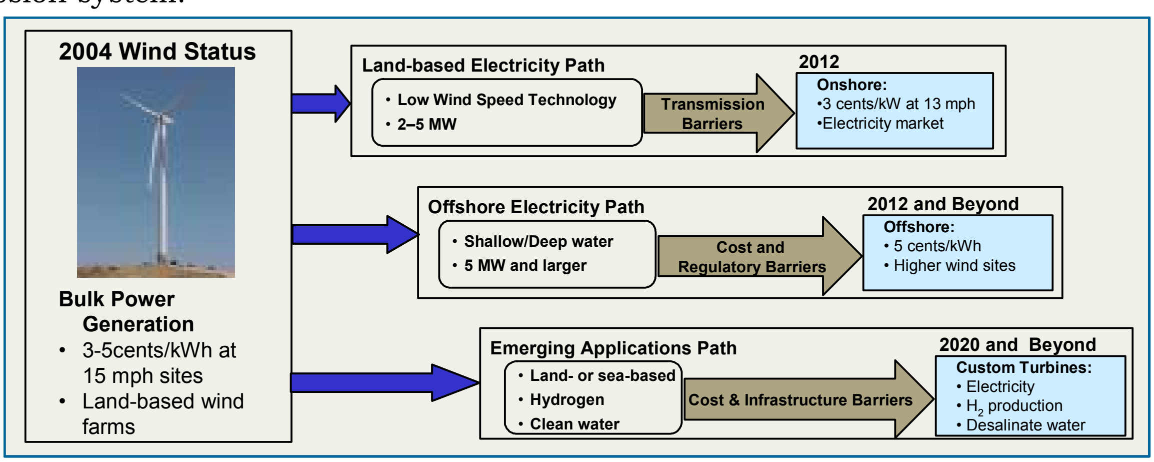


Figure 2. Three Evolution Pathways for Utility-Scale Wind Technology

Many of America's low wind speed sites are located in America's heartland on farms, ranches, and in rural communities from central and northern Texas to the Canadian border. Class 4 sites are also found along many coastal areas, including the Great Lakes. Figure 3 shows the abundance of lower wind sites and illustrates the 20-fold greater potential for wind in the U.S. if those sites can be used cost-effectively. These sites are also significantly closer to the major load centers than Class 6 sites. The current average distance between Class 6 resource areas and the 50 largest load centers is nearly 500 miles. The average distance for most Class 4 sites is about 100 miles. Reducing that distance could significantly lower transmission costs and the need for additional transmission infrastructure.

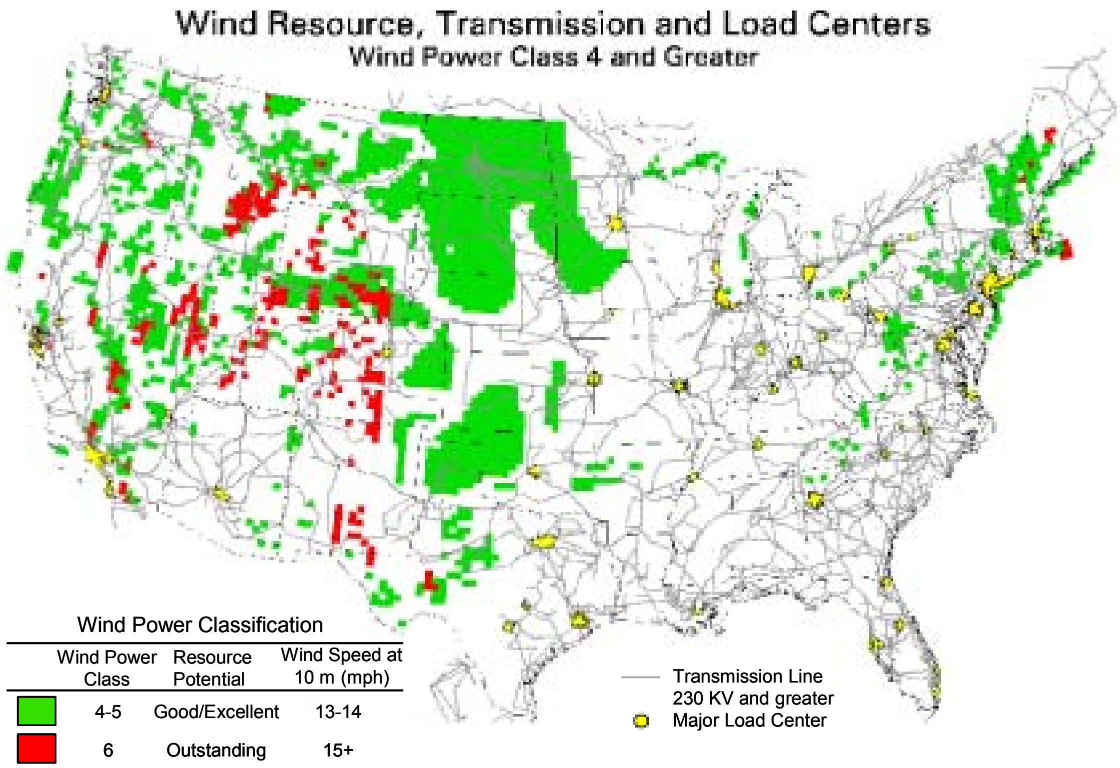


Figure 3. Wind Resource, Transmission, and Load Centers

Offshore Electricity Path – The second evolution pathway envisioned is a migration of current technology to offshore sites. At first, this will be into relatively shallow waters, and then later into deeper waters. These turbines are expected to be significantly larger – in the 5 MW and greater range. The program has a goal of 5 cents/kW for Class 4 shallow water sites by 2012, and is currently evaluating what goal might be appropriate for deep water technology. As the technology progresses along this pathway, other than cost, regulatory (siting) barriers are likely to be the most significant obstacles to offshore development.

To date, offshore wind developments have been limited to waters shallower than 30 meters in the North and Baltic Seas. At these depths, established foundation technologies can be used without significant additional R&D efforts. Preliminary estimates conducted at NREL indicate that there is over 900 GW of offshore wind energy potential in the United States outside 5 nautical miles, with approximately 810 GW over water that is 30 m and deeper. International research indicates that wind resources increase with the distance from the shore. Further, one of the key drivers of developing this higher-density wind power resource is to greatly reduce or eliminate the potential visual impacts encountered near shore. However, new technologies will be needed before deep water wind turbines can be deployed economically and safely. Deeper water installations will require alternative substructures to support the turbines. Advanced offshore turbines may utilize alternative lightweight materials and have operational characteristics that may actually benefit from the unique deepwater offshore environment. The program has begun the process of formulating a focused deep water wind energy technology R&D program.

Emerging Applications Path – The third evolution pathway leads toward the design of turbine systems tailored for emerging applications like hydrogen production or for the production and delivery of clean water. The production of hydrogen would open up an opportunity for wind to provide low cost, clean energy for the transportation sector. Both of these applications present significant new challenges to the wind community, and cost and infrastructure barriers are expected to be significant. The program's vision is that this evolution pathway will begin to have an impact on the marketplace in the post-2020 timeframe.

3.2 Goals and Objectives

3.2.1 National Needs

The United States faces many challenges as it prepares to meet its energy needs in the twenty-first century. Electricity supply crises in California, fluctuating natural gas and gasoline prices, heightened concerns about the security of the domestic energy infrastructure and of foreign sources of supply, and uncertainties about the benefits of restructuring are all elements of the energy policy challenge.

3.2.2 DOE Goals

The Department of Energy Strategic Plan (September 30, 2003) describes four strategic goals in support of achieving the Department's mission. These goals are in the areas of defense, energy, science, and the environment. The Energy Strategic Goal is the most relevant to the Wind Program. All of the Wind Program's efforts support that goal, as shown in Figure 4.

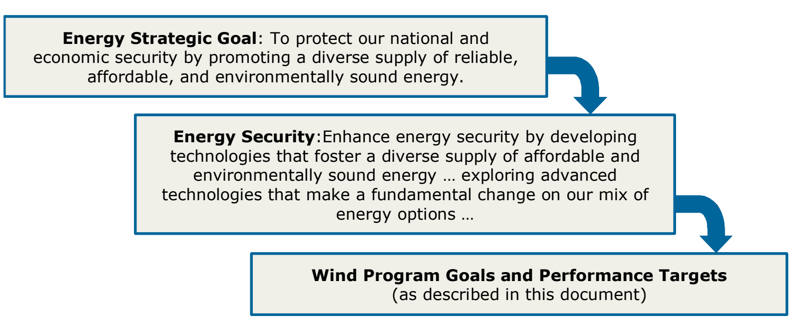


Figure 4. Relationship of Wind Program Goals to DOE Strategic Goals

3.2.3 Office of Energy Efficiency and Renewable Energy Goals

The Office of Energy Efficiency and Renewable Energy (EERE) leads the Federal government's research, development, and deployment efforts in energy efficiency and renewable energy. EERE's Strategic Plan, published in October 2002, describes nine strategic goals. These include reducing dependence on foreign oil, reducing the burden of energy prices on the disadvantaged, increasing the efficiency of buildings and appliances, reducing the energy intensity of industry, and creating a domestic renewable energy industry. Most relevant to the Wind Program is the priority to:

> *Increase the viability and deployment of renewable energy technologies, by improving performance and reducing costs, and by facilitating market adoption of renewable technologies.*

3.3 Wind Program Mission and Goals

Responding to these national energy policy priorities, the Wind Program has recently begun charting new directions for its efforts. These directions are being organized around the two thrusts described by the Assistant Secretary for Energy Efficiency and Renewable Energy. They are:

- *Increasing the viability of wind energy* - developing new cost-effective technology for deployment in less-energetic, Class 4 wind regimes; developing cost-effective distributed, small-scale wind technology; and performing research that supports these technology viability activities.
- *Increasing the deployment of wind energy* - helping facilitate the installation of wind systems by providing supporting research in power systems integration, technology acceptance, systems engineering, communication and analytical support.

The wind program research portfolio includes both near-term and long-term focused research to provide a balance between the need to work with industry to solve pressing short-term technical issues and the need to maintain U.S. industry momentum as a technological innovator. Balancing this portfolio and assuring that a variety of approaches exist to achieve the goals are the challenges of the program planning function.

3.3.1 Program Mission

The Wind Program's mission is to "*support the President's National Energy Policy and Departmental priorities for increasing the viability and deployment of renewable energy; lead the Nation's efforts to improve wind energy technology through public/private partnerships that enhance domestic economic benefit from wind power development; and coordinate with stakeholders on activities that address barriers to use of wind energy.*"

3.3.2 Program Goals

The program has defined goals for its technology viability and technology application activities that will position wind as an attractive advanced technology option for the twenty-first century. These goals are:

- By 2012, reduce the cost of electricity from large wind systems in Class 4 winds to 3 cents/kWh for onshore systems and 5 cents/kWh for offshore systems.
- By 2007, reduce the cost of electricity from distributed wind systems to 10-15 cents/kWh in 2007 in class 3 wind resources, the same level that is currently achievable in class 5 winds
- By 2012, complete program activities addressing electric power market rules, interconnection impacts, operating strategies, and system planning needed for wind energy to compete without disadvantage to serve the Nation's energy needs.
- By 2010, facilitate the installation of at least 100 MW of wind energy in 30 states.

3.4 Strategic Planning

Figure 5 provides an overview of the program's strategic planning framework, which has two elements. First, the program has an on-going Technical Assessment activity – to monitor the current status of wind technology and progress in achieving program cost goals, to evaluate that status within the context of the needs of the marketplace, and to identify technological pathways that will lead to wind's successful competition in the marketplace. The program also uses a formal Peer Review process – to benefit from the guidance of industry and the research community, and to provide an outside view of the program. As shown in Figure 5, Technical Assessment and Peer Review provide inputs that the Program Management Team considers in making decisions about strategic program directions and funding priorities. The Technical Assessment and Peer Review activities are described in the following sections.

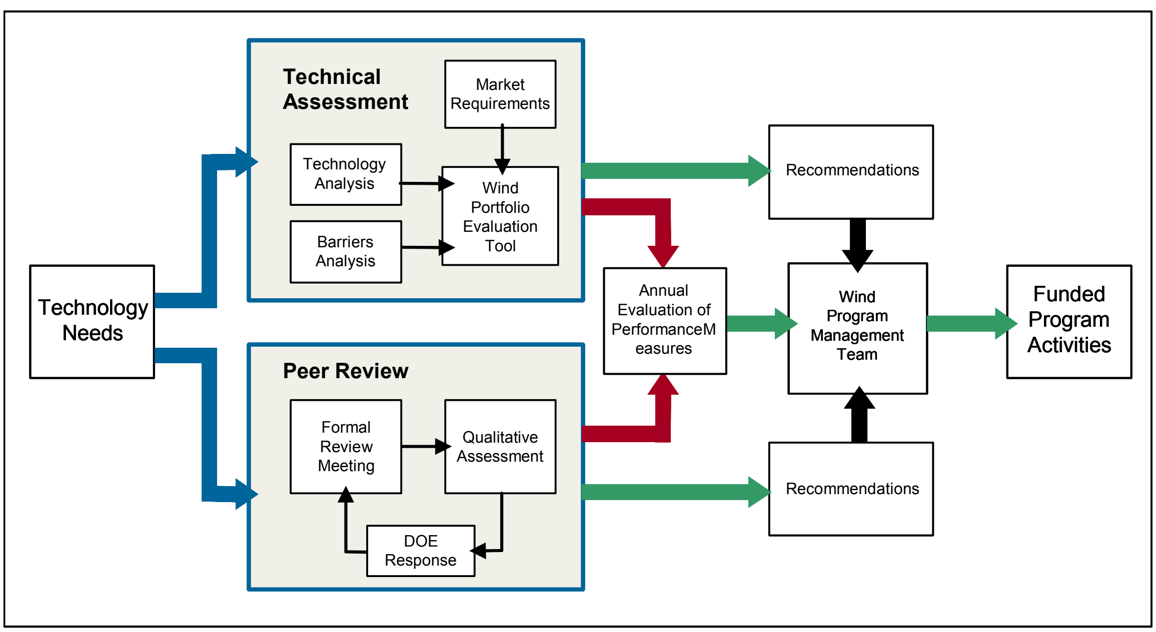


Figure 5. Strategic Planning Framework

3.4.1 Technical Assessment

The technical assessment process ensures that every research activity supported by the program can be demonstrated to have a direct link to achieving the top-level objectives and goals of the Wind Program, the Office of Energy Efficiency and Renewable Energy, and DOE. The technical assessment process is outlined in Figure 6 and described in more detail in Appendix A.

The technical assessment effort is built around a Technology Pathways structure. In developing the focus on Class 4 resources, program researchers, technical consultants, and peer reviewers have defined a 2002 Reference Turbine configuration, against which R&D progress is being measured. This 2002 Reference Turbine is the beginning point for the pathways analysis and the reference point for the technical assessment activity. The Technology Pathways analysis structure is used to assess all program support for technology development, as will be described in Chapter 5.

The technical assessment process can be described as including three steps:

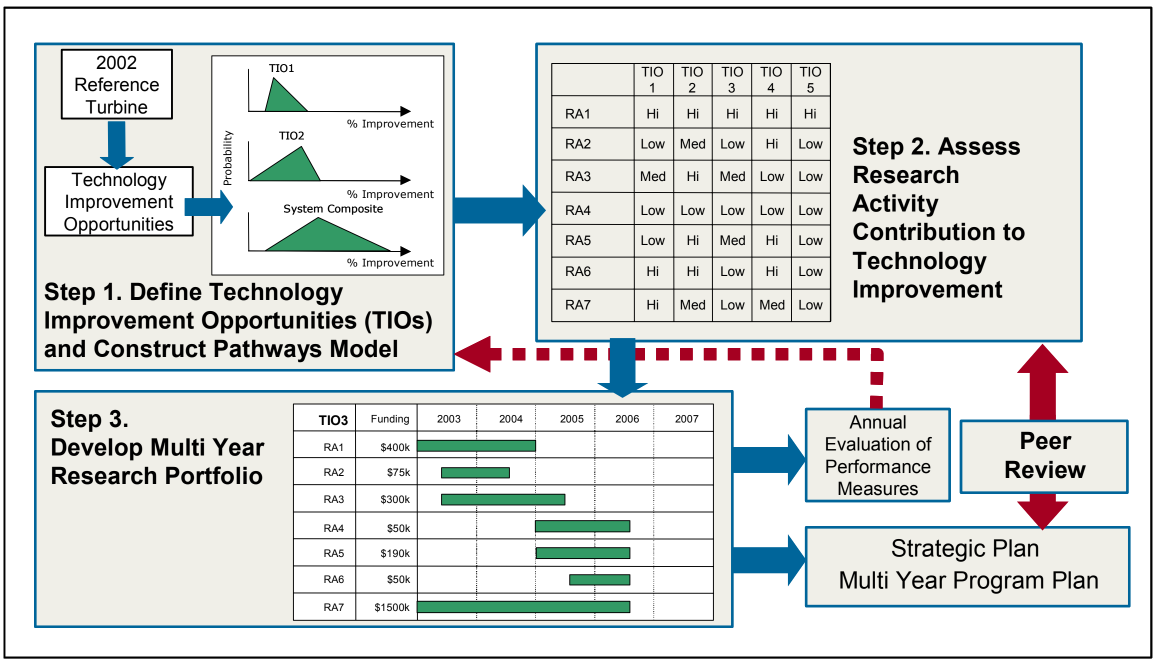


Figure 6. Technical Assessment Process

1. Characterization of Technology Improvement Opportunities – In this step, the program identifies areas of possible cost reduction or performance enhancement to the reference configuration, or Technology Improvement Opportunities (TIOs). Examples of TIOs include rotor efficiency enhancements, taller towers, and reduced design margins. These improvements are then further assessed, using the Wind Technology Pathways Model, to quantify their potential contribution to improving the technology's cost-effectiveness. Cost of energy is used as a focus for this analysis because it captures the capital investment cost and performance trade-offs facing turbine designers. Appendix A provides a detailed discussion of the Wind Technology Pathways Model.
2. Research Activity Prioritization and Performance Goals – In this step, program planners identify the research activities necessary to achieve the TIOs. Each re-

search activity's potential contribution to technology improvement is identified. Research activities that contribute little to achieving technical targets (such as RA4 in the example figure) are terminated. Those contributing the most are given the highest funding and management priority.

3. Detailed Portfolio Planning – Finally, after developing a prioritized list of research activities, program planners then formulate the program's research plan over the planning horizon.

An important element of the Technical Assessment process is to perform annual assessments of progress toward program goals, and to incorporate peer review feedback into program prioritization activities. The analyses conducted under this Technical Assessment activity are also used in program estimates of annual benefits under the Government Performance and Results Act (GPRA).

3.4.2 Peer Review

In May of each year, the Wind Program holds its formal peer review. The peer review process provides a means for the program to receive formal feedback on its efforts. Peer reviews are conducted in a manner that conforms to Departmental guidance for the conduct of peer reviews. The results of the review are considered when the management team evaluates potential adjustments to program direction. A senior program advisor, who has strong technical credentials but is not directly affiliated with the program or any of the programs' contractors, manages the peer review process. This Peer Review Director works with program personnel to select the peer review team, which typically has five to ten members.

The Peer Review Meeting is an intensive three to four day technical event with topical sessions structured around major program research efforts. The presentations are open to all invitees (including staff from headquarters, the labs, contractors, etc.). Speakers make formal presentations on their research programs and then are subjected to questions. The Peer Review Panel is facilitated in its deliberations, and presents its findings in the Peer Review Report. During the summer, peer review efforts are incorporated into the portfolio evaluation effort. In the fall, the program reconvenes the peer review team to reach an understanding about program priorities and direction.

3.4.3 Performance Measurement and Strategic Assessment

The program uses a formal performance measurement and technology tracking process to guide multi-year planning and to realize the benefits of performance-based management. The Wind Technology Pathways approach, described in Section 3.4.1 and Appendix A, is also used for this progress measurement process. As described in Chapter 4, the program has identified four goals that encompass all of the program's activities. Tracking annual progress toward meeting these goals is an important element of the program's performance measurement strategy. Specific details about how each of these four is defined, and how they will be tracked, are found in Sections 5.1.2, 5.2.2, 6.1.2, and 6.2.2.

3.4.4 Program Planning and Implementation Documents

The combined efforts of the Technical Assessment and the Peer Review result in four key program documents:

- Strategic Plan – a broad statement of the program's goals, objectives, and priorities.
- Multi Year Program Plan – a detailed description of program activities and schedules, milestones, and performance metrics for each Research Activity. Like the Strategic Plan, the Multi Year Program Plan is a forward-looking document. Both documents require assumptions to be made about future funding levels.
- Annual Operating Plan– a specific plan for the current operating year. The AOP is different from the Strategic Plan and the Multi Year Program Plan in that it reflects the actual funding levels of the current year and the current status of research efforts.
- Annual Turbine Technology Update – an annual report on progress made from the 2002 reference turbine baseline technology toward program technology performance goals.

4.0 Technical Plan Overview

The Wind Program focuses on the dual elements, or Key Activities, of its mission – to increase the technical viability of wind systems and to increase their deployment in the emerging marketplace. Figure 7 shows that there are six subkey activities in these two elements.

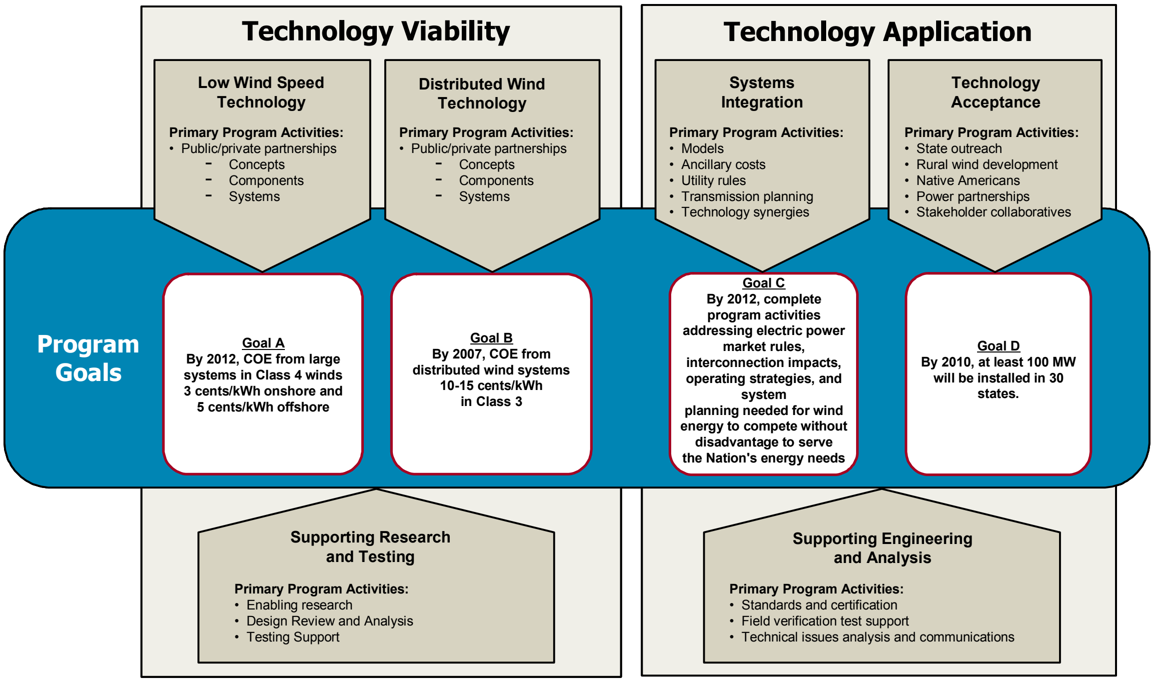


Figure 7. Wind Program Structure

For Technology Viability, the program is pursuing low wind speed technology, distributed wind technology and supporting research and testing to achieve continued progress in the two technology development areas. To increase Technology Application, the program sponsors research on systems integration, technology acceptance, and systems engineering and analysis. Figure 7 also lists the Research Goal for each subkey activity and provides a brief summary of primary research efforts in each area.

Table 1 provides a key activity-level summary of the funding profile assumed for this plan. Details are provided in Sections 5.0 and 6.0. The profile shown assumes a relatively constant total funding level. Because final funding decisions are made by the Department of Energy on a year-by-year basis, this projection will be revisited annually.

Table 1. Multi Year Funding Profile for Wind Program (millions $)

Key Activity	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
Technology Viability	29.6	31.0	31.8	31.1	32.1	32.1	32.6	32.6	32.6
Technology Application	10.0	10.6	9.8	10.5	9.5	9.5	9.0	9.0	9.0
Total	41.6		41.6	41.6	41.6	41.6	41.6	41.6	41.6

5.0 Technology Viability

The Technology Viability research efforts focus on helping industry to develop technology that will improve the cost-effectiveness of large and small wind energy systems. For program management purposes, and to assure appropriate high-level management focus on these activities, the Technology Viability key activity is managed as three separate subkey activities: 1) Low Wind Speed Technology (LWST); 2) Distributed Wind Technology (DWT); and 3) Supporting Research and Testing (SR&T).

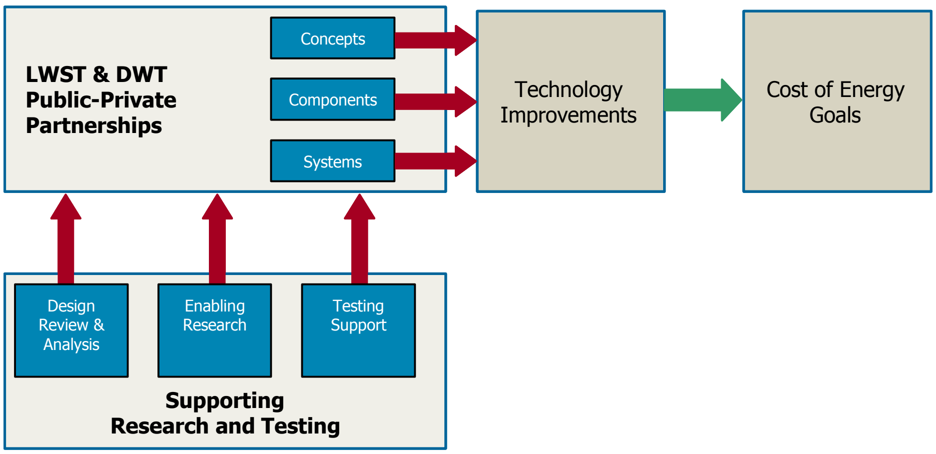


Figure 8. Interrelationships Among Technology Viability Activities

The three Technology Viability subkey activities are closely interrelated. Figure 8 shows the interrelationship between the LWST and DWT subkey activities and the SR&T subkey activity.

As Figure 8 shows, success in reaching the cost goals will result primarily from the efforts of industry through the public-private partnerships sponsored by DOE. While industry partners will have the primary responsibility for those efforts, program research staff will play an important enabling role. This supporting role can take several forms, and, depending on the specific project, might include project oversight, supporting analysis, testing support, or other enabling technical support that brings specialized expertise, which the industry partners might not have in-house, to bear.

Reductions in the COE from current levels to the goal level will not occur as a result of one single change in turbine configuration, or particular technology breakthrough. Those reductions will come from the combined contributions of many different, smaller advances. As will be described in more detail later, industry partners have identified a variety of technology and hardware approaches that could contribute to this lowering of the COE, and have proposed to pursue these changes in their partnerships with DOE. The program refers to these as Technology Improvement Opportunities (TIOs). As the program tracks progress toward the COE goal, it also tracks progress against each of the TIOs. Appendix A provides a more detailed description of how TIO progress and COE progress are inter-related and tracked.

The program tracks and reports annual progress in COE reduction through a process program researchers have named the “Annual Turbine Technology Update.” In this

Multi Year Program Plan, COE reductions, and the Annual Turbine Technology Update, are used as the performance measure for Technology Viability activities.

The remainder of this chapter describes the program's plan for Technology Viability. Table 2 provides a detail of the annual funding assumptions for subkey activities under Technology Viability. Because program funding allocation decisions are made annually, these values may be adjusted each year and do not in any way represent a commitment by the program to future funding.

Table 2. Multi Year Funding Profile for Technology Viability (millions $)

Key Activity	FY04	FY05	FY06	FY07	FY08	FY09	FY10	FY11	FY12
Low Wind Speed Technology	11.8	12.0	14.0	13.3	14.3	14.3	14.8	14.8	14.8
Distributed Wind Technology	1.9	2.0	2.0	2.0	2.0	2.0	2.0	2.0	2.0
Supporting Research and Testing	16.0	17.0	15.8	15.8	15.8	15.8	15.8	15.8	15.8
Total	29.7	31.0	31.8	31.1	32.1	32.1	32.6	32.6	32.6

5.1 Low Wind Speed Technology

The Low Wind Speed Technology (LWST) subkey activity is advancing the development of technology that will allow wind to compete in Class 4 (average wind speeds of 5.8 m/s at 10 m height) wind regimes. The availability of technology that can compete in these wind regimes is important to wind's continued expansion in the U.S. due to the wide-spread availability of Class 4 wind resources, both onshore and offshore.

5.1.1 Goal

The research goal of the Low Wind Speed Technology subkey activity is: "By 2012, reduce the cost of electricity from large wind systems in Class 4 winds to 3 cents/kWh for onshore systems and 5 cents/kWh for offshore systems."

5.1.2 Technical Challenges

The challenges faced by industry in developing new technologies are many. Innovative or advanced technologies are expected to be major contributors to future machine designs. Technologies that address the opposing design requirements of weight, cost, and reliability are essential to wind's continued growth. Ultimately, a much better understanding of the design and safety factor tolerances driving cost and reliability must be achieved if advanced turbine system designs are to be truly optimized.

In the 1970s and 1980s wind turbines used classical control designs to regulate power and speed. The methods used, however, were not always successful. These systems often had bandwidths large enough to destabilize low-damped flexible modes leading to high dynamic load fatigue failures. Modern turbines are larger, mounted on taller towers, and are more dynamically active than their predecessors. Control systems to regulate turbine power and maintain stable closed-loop behavior in the presence of turbulent wind inflow will be critical for these designs. New advanced control approaches and paradigms must account for low-damped flexible modes in order to reduce structural dynamic loading and achieve the 20-25 year operational life required of today's machines.

Competitive COE levels for wind have been achieved to-date by focusing development on Class 6 sites and by taking advantage of the federal Production Tax Credit (1.8 cents/kWh in 2003 $). With favorable financial terms, wind farms at Class 6 sites can market electricity at prices of 4 cents/kWh or less, without the subsidy. However, many Class 6 sites are located in remote areas that do not have easy access to transmission lines. In addition, as more and more sites have been developed, prime Class 6 sites that are easily accessible are becoming scarce. The full development of accessible Class 6 sites may cause wind energy growth to plateau in the near future unless improvements in technology can make lower wind speed sites more cost effective.

To this date, wind turbine designers and manufacturers have had little need to look beyond designing for Class 6 sites. This has allowed them to proceed with a steady progression toward larger rotor diameters and incrementally lower costs. By pursuing incremental design changes, they have also been able to lessen design risk. However, studies conducted under the WindPACT project indicate that more complex design improvements will be required to achieve the greater decreases in COE needed to achieve the DOE goals. These design improvements represent opportunities as well as significant challenges.

Wind turbines are currently capable of producing electricity at 4.5-5.5 cents/kWh in the Class 4 wind regimes that are broadly available across the United States, depending on many factors including project financial structure. Class 4 wind resources in the U.S. are relatively well characterized. However, current turbine designs are not well-suited to low wind regimes and have only limited potential to achieve lower costs of energy. The WindPACT projects have identified a broad range of concepts that have been demonstrated in studies to reduce the overall cost of energy. Given this potential, the challenge now remains of reducing those concepts to practice. Many wind energy companies are using the WindPACT studies as a guide to the selection of advanced technologies for development.

Program researchers can currently envision many potential technological responses to the challenges presented by operation in Class 4 winds. For instance, advanced drive trains will incorporate rare earth permanent magnets for generator excitation. They will use novel drive train configurations such as reduced gearbox stages and low speed and medium speed generators. Advanced power electronics will allow variable speed operation while improving overall drive train and power conversion efficiency. Such power converters will also allow higher quality power for electrical grid connection. Advanced rotors may be field assembled, have a lower blade chord (width) and run at higher tip speeds to reduce rotor loads. They will be made from advanced materials such as carbon fiber, and may incorporate passive control mechanisms. Advanced controls will help to improve performance and reduce system loads while monitoring overall system health contributing to reductions in maintenance cost. Higher rotor blade tip speeds will challenge designers to reduce aeroacoustic emissions. To take advantage of higher velocity winds at higher altitudes, new towers will be developed that are less expensive, are made of advanced materials, and can be assembled onsite to reduce transportation costs. Such towers may also provide for self erection to reduce the significant costs associated with placing turbine nacelles on taller towers. Advanced designs must also account for poorly understood turbulence and velocity changes associated with nocturnal jets as they dip to within wind turbine operating heights.

While the technical issues associated with onshore LWST turbine development are relatively well understood and a fairly well defined approach can be identified, the same cannot be said for offshore wind technology. Current design concepts and visions are based upon limited experience with sheltered shallow water sites. Costs associated with offshore technology currently run 1.3 to 1.5 times higher than onshore developments, or 7-8 cents/kWh. U.S. experience is literally nonexistent though several projects have been proposed and are in the preliminary stages of development. U.S. locations with significant resources do not match previously developed European sites well. Many of the U.S. sites will require the application of technologies that have yet to be explored or seriously considered in Europe, especially those that will allow development in deeper waters, which may have greater wind, wave and ice loading. In addition, numerous environmental, political and regulatory issues exist in the U.S., which must be dealt with in the near term before significant development can get underway.

In the area of offshore development, technical challenges include issues such as combined wind, wave and ice loading, geotechnical design issues (foundations, floating platforms, anchoring, and shifting ocean floor dynamics), and offshore transmission and interconnection issues. An improved understanding of the offshore environment, including impacts on avian populations and ocean mammals will be important. U.S. industries that specialize in ocean engineering, especially in deep water applications, will contribute a great deal of expertise in this arena. Every effort will be made to encourage teaming with these industries in developing and assessing these future applications.

5.1.3 Technical Approach

Strategy

The strategy of the LWST subkey activity is to use public/private partnerships to achieve technical advances in concept designs, component development, and full-scale prototypes. Figure 9 shows the LWST strategy. This work builds upon previous program efforts – the WindPACT advanced technology studies and the Next Generation Turbine program. The LWST partnerships are cost-shared efforts with industry. The completion of each partnership cycle represents an important Wind Program milestone. The strategy of using multiple rounds of solicitations serves three purposes. First, it allows multiple entry points, allowing industry partners to participate as each company's needs dictate. Second, it gives companies the opportunity to receive follow-on funding to pursue concepts or designs identified in earlier rounds. Third, it gives the program an opportunity to end support for a particular idea, at pre-determined stage gates, if it is not producing the expected results. As can be seen in the figure, the Supporting Research and Testing subkey activity provides critical support to the LWST effort, as will be discussed in Section 5.3.

Performance Measures

Levelized cost of energy (COE) will be used to measure progress in the LWST effort. The targeted output of this effort is a commercially available turbine prototype that produces electricity in Class 4 winds for 3 cents/kWh for onshore systems or 5 cents/kWh for offshore systems by 2012 (in constant levelized 2002 dollars). When the LWST effort was initiated, program researchers projected that improvements in COE might occur as shown as the "LWST Target" trajectory in Figure 10. Program researchers have identified eight categories of Technology Improvement Opportunities (TIOs) that will be the focus of program research and development. These TIOs, which are very specific ways to improve either cost or performance, are described in greater detail in Appendix A: Wind Research Portfolio Evaluation.

To understand how progress is being made against that target trajectory, the program con ducts an annual assessment known as the Annual Turbine Technology Update (ATTU). Figure 10 shows the results of this annual performance reporting process, as of the end of FY 2004.

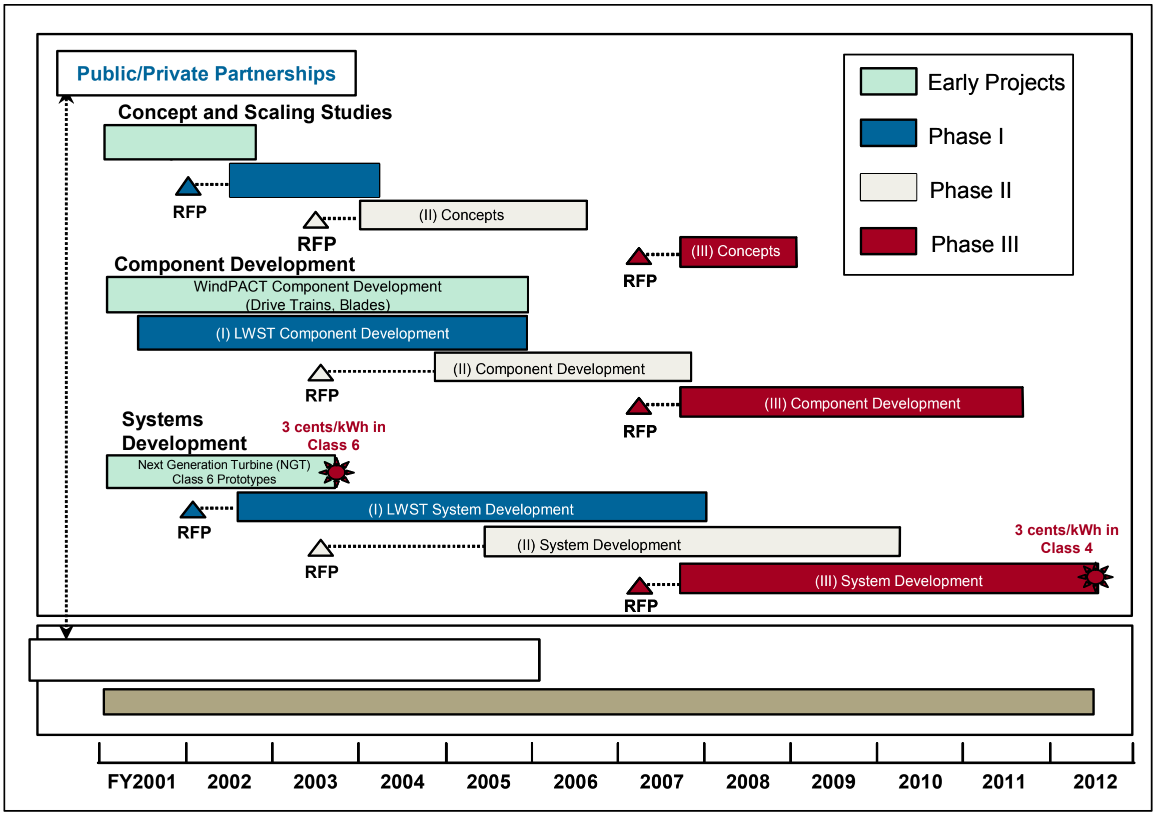
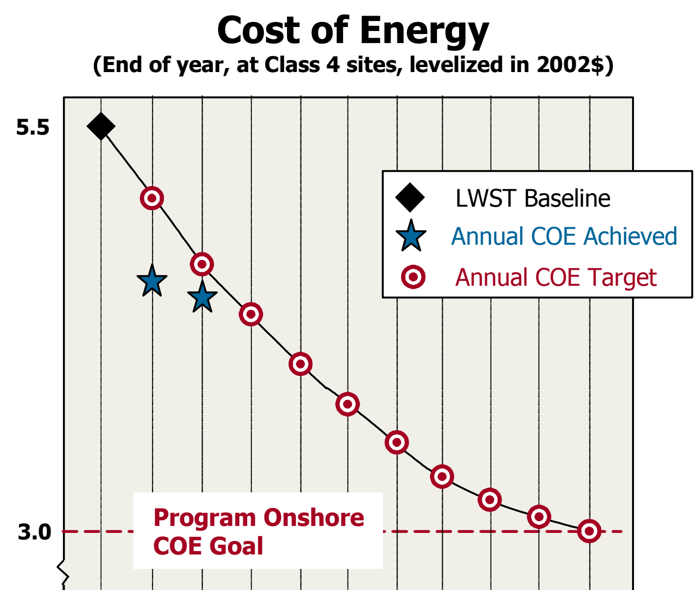


Figure 9. Low Wind Speed Technology Strategy

The ATTU assessment process is based on three key principles: 1) Full COE improvement is realized when a product is commercialized, at the level of 100 MW of installed capacity; 2) Progress toward COE improvement is measured by progress on the industry partnerships (i.e., development subcontracts) to develop new technologies; and 3) Different types of partnership efforts will mature the technology to different levels. Using these three principles, the ATTU process identifies projected COE improvements for each partnership, identified by TIO and broken down by the major elements that impact COE (TCC – Turbine Capital Cost; BOS - Balance of Station Cost; LRC – Levelized Replacement Cost; O&M – Operations and Maintenance Cost; AEP – Annual Energy Production). The contribution of each partnership is evaluated, based on the type of effort it represents. A conceptual study is given a very low value because it only results in a design concept. A component development effort is valued higher because it creates a piece of hardware that may be retrofit to a commercial machine. A prototype development is valued the highest, because it demonstrates a full system. The highest valuation is reserved for prototypes or components that achieve full commercialization. Progress on partnerships is measured by achievement of clearly defined milestones within each project, such as Detailed Design Reviews, Test Initiation or Test Completion, and defined as a percent complete. By combining the predicted improvement, project valuation and percent complete of the partnership, an assessment of the COE improvement achieved at a given time can be determined.

Figure 11 provides details of the ATTU assessment conducted for FY 2003 and FY 2004. The COEs that resulted from these assessments are listed in Figure 10 on the “COE Achieved” line of the graphic.

If the annual ATTU assessment determines that a particular research effort is not yielding the expected results, and is unlikely to contribute significantly to future COE reductions, the Wind Program will terminate the activity. The program's peer reviewers will be consulted, as described in section 3.4.2, when such determinations are being made.



(in cents/kWh)	2002	2003	2004	2005	2006	2007	2008	2009	2010	2011	2012
LWST Project Targets	5.5	5.0	4.6	4.3	4.0	3.7	3.5	3.3	3.2	3.1	3.0
ATTU	4.8*	4.5	4.4								

****ATTU Reference Turbine***

Figure 10. Example of Wind Turbine Technology COE Tracking Process

5.1.4 Research Activities

In 2001, the Wind Program launched a major new effort to reach the LWST goal. The program currently envisions that the LWST project will represent an increasingly larger portion of total program funds over the remainder of this decade. The strategy for the LWST project was developed in cooperation with industry, and guided by several principles:

- Public/private partnerships will be developed to support continuing innovation. They will be flexible and adaptive, support multiple pathways, have clearly defined stage gates for program termination, and offer repeated opportunities for new players to enter the program.
- Both onshore and offshore technology will be eligible for funding.
- Program research and testing activities will be closely aligned to support public/private partnerships.
- Applied systems integration activities will guide portfolio planning and technology transfer.
- Program evaluations using performance-based management techniques will provide a strong analytical basis for performance criteria, periodic review, and stage gate decisions.

The LWST project will have three phases of open solicitations for the development of advanced technology (as seen in Figure 9). In general, each of the three phases will allow industry participation in three types of projects. The first type is for conceptual design studies. Design studies offer an industry partner an opportunity to determine the probable

Annual Turbine Technology Update

Through the Wind Energy Technology Pathways Analysis, the Wind Program has established a projected trajectory of COE improvement to achieve the onshore Low Wind Speed Turbine (LWST) goal of three cents/kWh in Class 4 winds by 2012. This process is described elsewhere in the Multi Year Program Plan. As part of this process a set of Technology Improvement Opportunities (TIOs) were established to identify the advances that were expected to lead to the LWST Goal. The program has implemented the Annual Turbine Technology Update (ATTU) process, whereby the program can evaluate its yearly progress toward achieving the LWST goal.

2003 ATTU Projection

The 2003 projection, provided below, was developed using this methodology. This was the first year of projections, and the improvement is dominated by the commercial success of the GE 1.5 MW 77-meter turbine, developed under the program's NGT program. This turbine took advantage of advanced active controls to reduce loads, thereby allowing the lengthening of the rotor without adversely affecting other major components. The successful commercialization of this machine caused a significant COE improvement.

Technical Improvement Opportunity	Predicted Improvement (Percent)	Cumulative Improvement To Date	Current Year Improvement	Improvement from Prior Year (Percent)	COE Improvements (US Dollars)
Advanced (Enlarged) Rotors	21.23%	5.94%	5.94%	0.00%	$0.0029
Manufacturing	2.07%	0.00%	0.00%	0.00%	$0.0000
Reduced Loses and Increased Availability	5.75%	0.12%	0.12%	0.00%	$0.0001
Advanced Towers	4.37%	0.12%	0.12%	0.00%	$0.0001
Site-Specific Design/Reduced Design Margins	28.54%	0.00%	0.00%	0.00%	$0.0000
New Drive Train Concepts	3.69%	0.74%	0.74%	0.00%	$0.0004
Advanced Power Electronics	6.02%	0.41%	0.41%	0.00%	$0.0002
Learning Curve Effects	5.82%	0.00%	0.00%	0.00%	$0.0000
				Total Reduction	$0.0037
				Reference COE	$0.0480
				New COE	$0.0443

2004 ATTU Projection

The 2004 projection, provided below, shows a minimal improvement over 2003. This is due the fact that during 2004 LWST efforts focused on the negotiation and award of a new block of LWST subcontracts. While many of the subcontracts have started, they are much too early in their development process to impact COE greatly. The LWST subcontracts that were still in place during 2004 from 2003, made limited progress, as major components were being fabricated for testing, but will not complete their final testing until later in 2005.

Technical Improvement Opportunity	Predicted Improvement (Percent)	Cumulative Improvement To Date	Current Year Improvement	Improvement from Prior Year (Percent)	COE Improvements (US Dollars)
Advanced (Enlarged) Rotors	21.23%	6.16%	0.22%	0.22%	$0.0030
Manufacturing	2.07%	0.14%	0.14%	0.14%	$0.0001
Reduced Loses and Increased Availability	5.75%	0.21%	0.08%	0.08%	$0.0001
Advanced Towers	4.37%	0.21%	0.08%	0.08%	$0.0001
Site-Specific Design/Reduced Design Margins	28.54%	0.00%	0.00%	0.00%	$0.0000
New Drive Train Concepts	3.69%	0.93%	0.19%	0.19%	$0.0004
Advanced Power Electronics	6.02%	1.38%	0.97%	0.97%	$0.0007
Learning Curve Effects	5.82%	0.00%	0.00%	0.00%	$0.0000
				Total Reduction	$0.0044
				Baseline COE	$0.0480
				New COE	$0.0436

Figure 11. Results of Annual Turbine Technology Updates

value of a particular concept by performing a paper analysis before undertaking detailed
design and fabrication. These small scale studies (approximately $200,000) are non-cost-shared and the results are in the public domain. These studies are intended to lead a developer to the next round of solicitations, where they may choose to more fully develop their idea. The second type of project is a cost-shared component development project. In this type of project, the industry partner completes detailed design and testing of an advanced prototype component or subsystem. Such components are expected to reduce the cost of an existing design, or to serve as the basis for an entirely new prototype design. The third type of project calls for the cost-shared detailed design, fabrication and testing of an advanced prototype turbine. These turbines will be tested in field environments that demonstrate the likelihood of achieving the LWST goal.

Each subsequent phase of solicitations offers an opportunity for a team that has developed a concept or component to complete their development cycle by developing a complete turbine prototype. This three-phased approach with three different types of projects allows the
program to develop a broad portfolio of technologies and partners. Such a broadening of the technology base provides a higher likelihood that the goals and objectives will be met in the projected time frame. Conversely, all partnership efforts are established with clearly defined tasks and deliverables. Task reviews are established at key points throughout each project to allow termination or redirection of projects that are not achieving their goals.

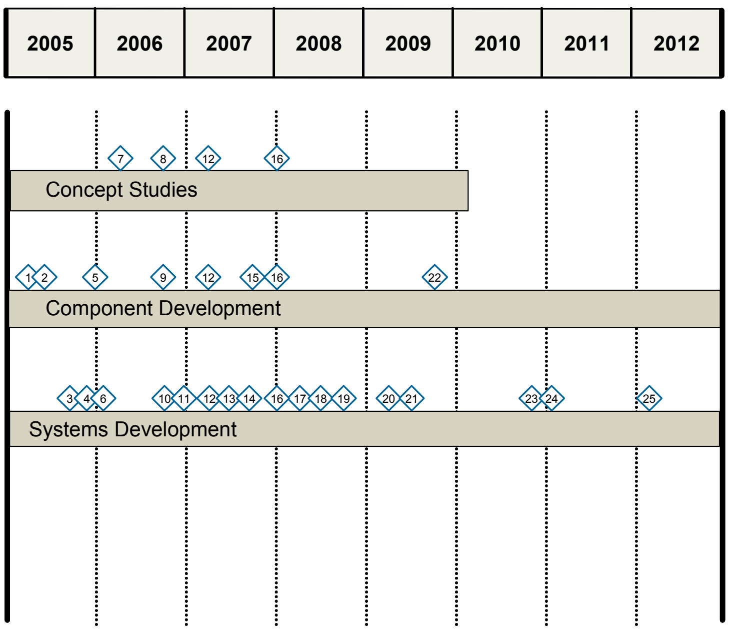
Activity Status – At the end of 2004, seven subcontracts were underway as part of the Phase I of the LWST solicitations. Two conceptual design studies had been completed. The subcontracts still underway include two drive train (gearbox and generators) developments, one power electronics/power conditioning project, two advanced blade development, and two full-scale advanced prototypes. Under the Phase II LWST solicitation for land based technologies, six conceptual design studies have been awarded and begun work, and an additional eight subcontracts are under negotiation in anticipation of funds availability in FY05 and later. Land-based subcontracts still under negotiation include one full-scale prototype, and five component development efforts (two advanced towers, one advanced gearbox, and two advanced blade developments), and two concept design studies. With respect to the offshore portion of the Phase II LWST solicitation, three conceptual design studies have been awarded and begun work, and two more subcontracts are under negotiation. Offshore subcontracts still under negotiation include one full-scale prototype, and one component development (one advanced blade development). Each of these subcontracts focuses on a technical area previously identified as having a high potential impact on COE reduction at low wind speed sites.

Technical Plan – Under the continuation of this effort, the project will issue one additional solicitation. This final solicitation is expected for 2007, with prototypes available for testing in the 2010 – 2011 timeframe. Component developments and concept studies will be completed along more compressed timelines, to exploit opportunities for accelerated transition to prototype systems, consistent with historically observed industry trends. This solicitation is expected to engage major industry partners in exploring the issues associated with developing low wind speed technologies for land based and offshore environments. The DOE program will use the WindPACT studies in helping to evaluate the likelihood that proposed projects will contribute to COE reduction. Because no set of studies can be all-inclusive, the program will evaluate new concepts as they are identified to determine their likelihood of contributing to COE reduction. All proposals provided by industry are required to estimate the COE reduction from any proposed technology, using a standard method. This approach facilitates the comparison of competing technologies, to assist in selecting those that offer the greatest return on DOE's R&D investment.

5.1.5 Milestones

Milestones for the Low Wind Speed Technology subkey activity provide planning guidance and a means by which progress can be tracked.

Low Wind Speed Technology



Milestones

1. Complete detailed design of advanced variable speed power converter.
2. Begin testing of advanced blade concept
3. Begin testing first full-scale prototype turbine.
4. Complete site selection for field testing first full-scale LWST prototype turbine.
5. Complete fabrication and begin testing of advanced variable speed power converter.
6. Begin field test first full-scale LWST prototype turbine from first round LWST solicitation.
7. Land-based concept studies completed.
8. Offshore concept studies completed
9. Begin testing of advanced components from second round LWST solicitation.
10. Complete test of first full-scale prototype turbine from first round LWST solicitation.
11. Complete detailed design of second public-private partnership project for full system development.
12. Issue third round LWST solicitation.
13. Begin testing second full-scale prototype turbine for onshore deployment from first round solicitation.
14. Complete detailed design of direct drive prototype turbine for onshore deployment from second round solicitation.
15. Complete testing passive load reduction blades from second round LWST solicitation.
16. Select public-private partnership participants from third round LWST solicitation.
17. Complete testing second full-scale prototype turbine for onshore deployment from first round solicitation.
18. Begin testing of direct drive prototype turbine for onshore deployment from second round solicitation.
19. Complete detailed design for first offshore shallow water prototype turbine.
20. Complete testing of direct drive prototype turbine for onshore deployment from second round solicitation.
21. Begin testing of full-scale prototype turbine for shallow water offshore deployment from second round solicitation.
22. Begin testing advanced components from third round solicitation.
23. Complete testing of full-scale prototype turbine for shallow water offshore deployment from second round solicitation.
24. Begin testing third round full-scale prototype

5.2 Distributed Wind Technology

The Distributed Wind Technology (DWT) subkey activity is working with the small wind turbine industry to develop advanced technology to make distributed wind technology cost-effective in much wider regions of the country, and for a wide variety of applications. Similar to the LWST, the DWT subkey activity is focusing on technological innovation that can lessen the requirement for average wind speed, moving the design focus from Class 5 to Class 3.

5.2.1 Goal

The research goal of the Distributed Wind Technology subkey activity is: "By 2007, reduce the cost of electricity from distributed wind systems to 10-15 cents/kWh in Class 3 wind resources, the same level that is currently achievable in Class 5 winds."

5.2.2 Technical Challenges

The U.S. small wind turbine industry offers a wide assortment of products for various applications and environments. Machines range in size from those that generate 400 watts (W) of electricity for specific small loads such as battery charging for sailboats and small cabins, to 3–10 kilowatt (kW) systems for residence, to those that generate up to 100 kW of electricity for large loads such as a small business and industrial operation. Small wind turbines can operate effectively in large portions of the rural areas of the United States. It is estimated by industry that small wind turbines could meet 3% of U.S. electricity consumption by 2020.

It is a substantial challenge to design, manufacture, and install small wind turbines that are low in cost and yet rugged enough to withstand 20 to 30 years of operation in weather that is often severe. Distributed wind turbine technology development is both an art and science. The true measure of a new design is often not known until several years of operation at dozens of sites. At present, there is no way to effectively duplicate the wear and tear of the real world during the product development stage. As a result, reliability has historically been the Achilles heel for small wind turbine technology.

Small wind turbines (machines of less than or equal to 100 kW), though seemingly simple, must overcome many of the same technical barriers as those facing larger utility-scale machines. Because of the need for simplicity and high reliability, small machines face other technical challenges. The importance of understanding small wind turbine performance has been identified in previous Wind Program activities. However, many issues remain poorly understood when it comes to the specific behavior of small wind turbines, such as furling or other overspeed control behavior, thrust measurements, yaw behavior, acoustic emissions and blade and tower loads.

In June 2002, the American Wind Energy Association released its "Roadmap: A 20-year industry plan for small wind turbine technology." The Wind Program's plan for DWT activities incorporates many of the Roadmap's recommendations.

5.2.3 Technical Approach

Strategy

The strategy of the DWT effort is to use public/private partnerships to help industry develop a cost-effective low wind speed small turbine that meets distributed energy needs. These partnerships may also develop cost-effective components such as inverters, rotors, and tall towers, and develop conceptual designs to guide future technology innovation. Figure 11 shows this strategy. As is the case for LWST research, the Supporting Research and Testing subkey activity provides important support to this effort. The DWT partnerships also allow multiple entry points, offer industry the chance to receive follow-on funding to pursue opportunities identified in previous rounds, and provide stage gate decision points for termination of unproductive efforts.

Performance Measures

The Wind Program has identified cost of energy (COE) as the primary indicator of progress in distributed wind technology development. Specifically, the Wind Program is seeking to reduce the COE from small wind systems to the point where they have the same cost effectiveness (10-15 cents/kWh) in Class 3 wind resources in 2007 as they currently have in Class 5 resources (Figure 12). The upper end of the COE goal range is for grid-connected residential-sized turbines, while the lower end of the range is for small commercial-sized turbines.

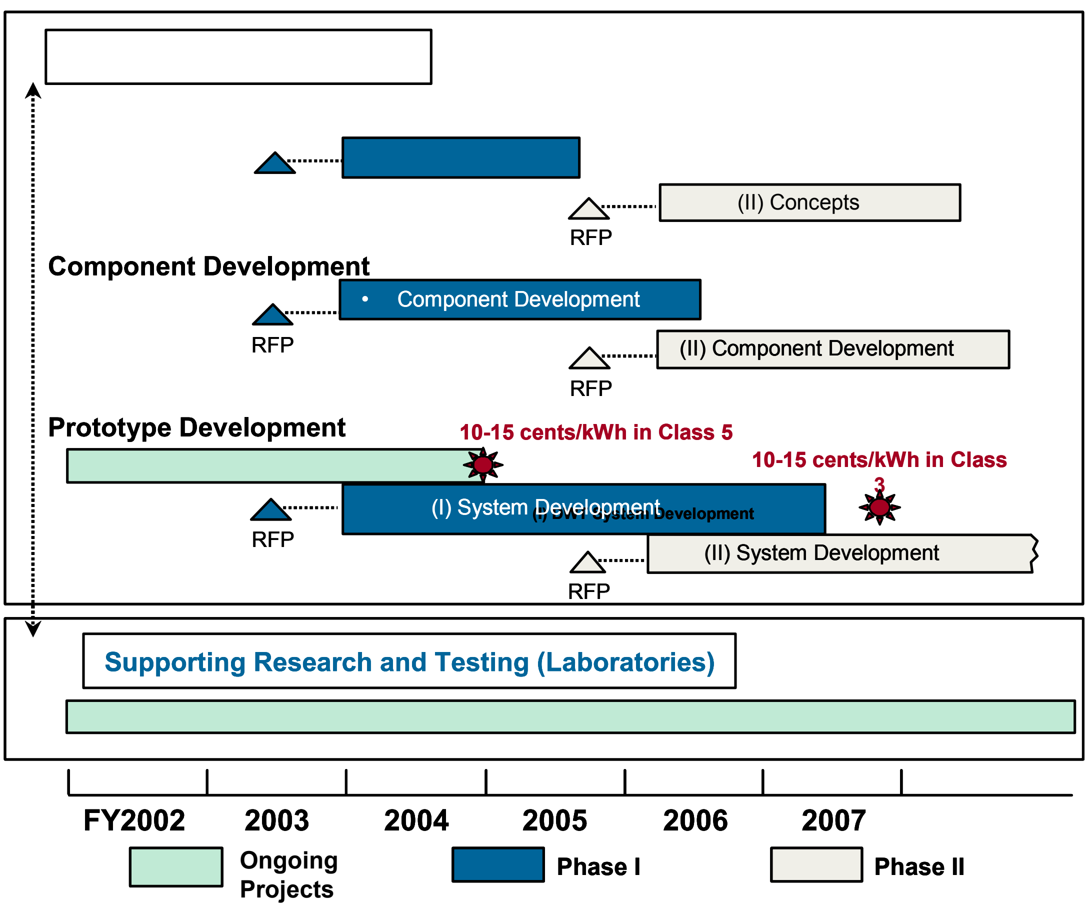


Figure 11. Distributed Wind Technology Strategy

Cost of energy is particularly appropriate for prototype development activities, since it embodies the full systems perspective required to create a commercially viable product. However, the program will develop performance goals for each development activity that it sponsors, recognizing that, in the smaller size range, there will be a wider variety of cost and performance specifications, depending on application, required levels of reliability, etc..

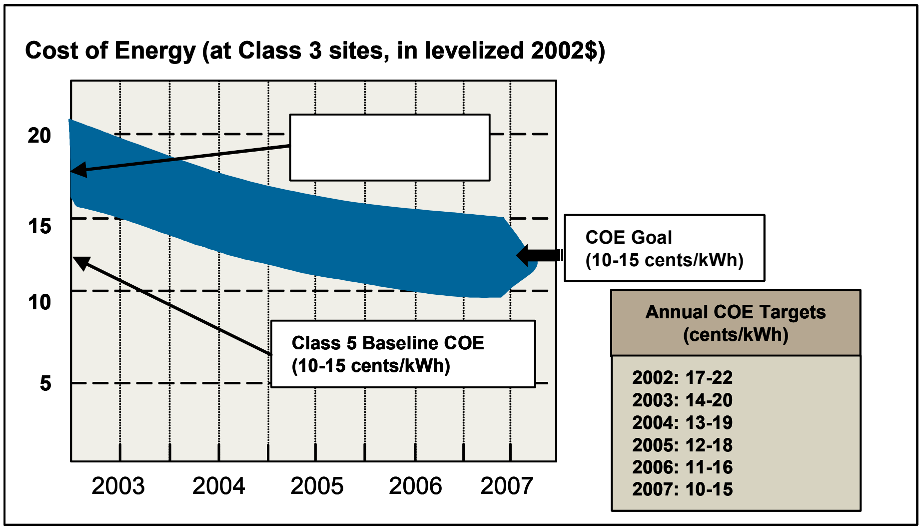


Figure 12. Distributed Wind Turbine Cost of Energy Tracking and Goals

5.2.4 Research Activities

The DWT subkey activity is pursuing the same broad objective as the LWST effort – to reduce the cost of energy of wind turbines (<100 kW for distributed turbine technology) at lower wind speed sites. In support of the DWT objectives, the program has announced a competitive solicitation for public/private partnerships to develop small turbine technology for lower wind regimes. The contracts with industry resulting from these public/private partnerships will be supported by a number of other necessary efforts, including design review and support, field testing, and laboratory testing.

The Wind Program coordinates its efforts with other elements of the Office of Energy Efficiency and Renewable Energy. In particular, the Distributed Energy and Electric reliability program provides support in the reduction of barriers to interconnection and utilization.

It is a substantial challenge to design, manufacture, and install small wind turbines that are low in cost and yet rugged enough to withstand 20 to 30 years of operation in weather that is often severe. Small wind turbine technology development is both art and science. The true measure of a new design is often not known until several years of operation at dozens of sites. At present, there is no way to effectively duplicate the wear and tear of the real world during the product development stage. As a result, reliability has historically been the Achilles heel for small wind turbine technology.

Activity Status – The program's support for distributed turbine technology builds upon prior cost-shared turbine development activities. In 2001, the program initiated the

Small Wind Turbine Development effort. The competitive solicitation for that project led to the selection of four companies to pursue advanced designs. These four designs are in various stages of development and testing.

In FY2003, the program issued a solicitation for proposals under the first round of funding under the new DWT public/private partnerships. The public/private partnerships will work to enhance design techniques and capabilities, particularly rotor aerodynamics and dynamics that are unique to small wind turbines.

Technical Plan – The DWT project will be implemented through a sequence of open solicitations (two phases) for the development of advanced technology (Figure 11). Each of the solicitation phases will consist of three types of projects in which industry can participate.

- The first type of project is for conceptual design studies. Design studies offer an industry partner an opportunity to determine the probable value of a particular concept by performing a paper analysis before undertaking detailed design and fabrication. These small scale studies (approximately $200,000) are non cost-shared and the results are public domain. These studies are intended to lead a developer to the next round of solicitations where they may choose to more fully develop their idea. Industry has identified improved subsystem integration as being a priority.

- The second type of project is a cost-shared component development project. In this type of project, the industry partner completes detailed design and testing of an advanced prototype component or subsystem. Such components are expected to help reduce the cost of an existing design, or to serve as the basis for an entirely new prototype design. Based on current technology status, the program expects that component efforts may focus on advanced airfoils, permanent magnet alternators or generators, foundation/anchoring systems, and tower designs.

- The third type of project calls for the cost-shared detailed design, fabrication and testing of an advanced prototype turbine. These turbines will be tested in low wind speed environments that are representative of Class 3 conditions and demonstrate the likelihood of achieving the DWT goals.

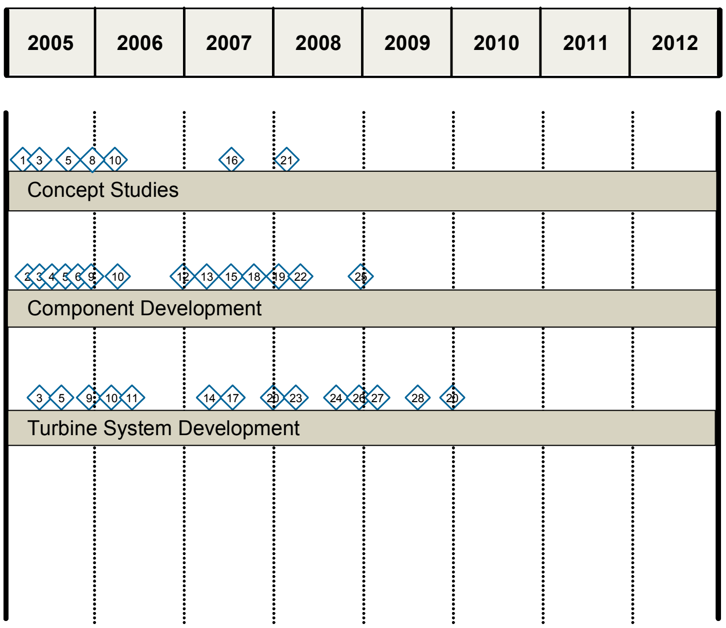
Each subsequent phase of solicitations offers an opportunity for a team that has developed a concept or component to complete their development cycle by developing a complete turbine prototype. This two-phased approach with three different types of projects allows the program to develop a broad portfolio of technologies and partners. Such a broadening of the technology base provides a higher level of likelihood that the goals and objectives will be met in the projected time frame. Conversely, all partnership efforts have clearly defined tasks and deliverables. Task reviews are established at key points in each project to allow termination or redirection of projects that are not achieving their goals.

In addition to the public/private partnerships, the program will pursue a number of research efforts that industry has identified in its Roadmap as being important for the ultimate success of small wind turbines. These are described in Section 5.3 "Supporting Research and Testing." It should be noted that the Roadmap outlines a wide variety of efforts, many of which are policy-focused and beyond the role of the DOE program.

5.2.5 Milestones

Milestones for the Distributed Wind Technology subkey activity provide planning guidance and a means by which progress can be tracked.

Distributed Wind Technology



Milestones

1. Complete one of the grants for DWT conceptual
2. Complete IEC Safety and Function Test on 1.8 kW wind turbine
3. Initiate next round of DWT solicitations for design, component and system
4. Complete IEC acoustic and power performance tests on 1.8 kW wind turbine
5. New procurement for concept design studies component and turbine system development
6. Complete IEC acoustic testing of 1.8 kW Small Wind Turbine, finishing the IEC suite of tests for acoustics, power, durability, and safety
7. Begin testing of one component under DWT
8. Complete all of the grants for DWT round conceptual design
9. Test one small wind turbine to the suite of IEC identified for small
10. Award grants/cooperative agreements for second of DWT
11. Begin testing of another component under DWT
12. Evaluate final design reports for one development
13. Evaluate final design reports for another development
14. Begin testing one DWT turbine developed under grant
15. Complete the preliminary design review for a round 2 grant
16. Complete one of the round 2 DWT concept studies
17. Complete a detailed design review of one of the round 2 DWT grants
18. Complete the preliminary design review for another round 2 grant
19. Begin testing program for round 2 DWT grants
20. Complete evaluations of turbine system work under round one of the DWT development
21. Complete another of the round 2 DWT concept studies
22. Complete a detailed design review of another of the round 2 DWT grants
23. Begin testing program for next round 2 DWT grants
24. Complete a detailed design review of another of the round 2 DWT grants
25. Complete round two DWT component development

5.3 Supporting Research and Testing

The Supporting Research and (SR&T) subkey activity supports the advancement of technology in those critical areas that have been shown to have the potential to reduce the cost of energy of large utility-scale and small distributed wind systems in low wind speed regimes. The SR&T effort brings specialized technical expertise, comprehensive design and analysis tools, and unique testing facilities to bear on problems that industry will encounter in bringing new wind technology to the marketplace.

5.3.1 Goal

The Supporting Research and Testing subkey activity provides targeted research and testing support to meet the needs of the Low Wind Speed Technology and Distributed Wind Technology research activities. Therefore, as a supporting activity, the goals of the SR&T effort are the same as the LWST and DWT subkey activities.

5.3.2 Technical Challenges

The development of advanced technology that will allow wind turbines to compete in lower wind regimes, or in new environments such as offshore, presents many technical obstacles. Cost and performance tradeoffs are increasingly becoming the focus of industry turbine designers. With a trend toward taller towers, to take advantage of generally stronger winds aloft, turbine manufactures are placing increasing emphasis on understanding turbine dynamics and on identifying and implementing strategies to control turbines in those dynamic environments. Turbines at higher hub heights, and with larger rotors, are also subject to unpredictable, and frequently turbulent, inflow. Such wind conditions make the turbine designer’s work even more difficult.

As was described in greater detail in Sections 5.1.2 and 5.2.2, there are many possible design responses to these technical issues. These responses are being explored in the LWST and DWT public/private partnerships being run by the Wind Program. As will be described in the remainder of this section, program researchers are providing a wide range of technical support to these partnerships.

5.3.3 Technical Approach

Strategy

The strategy of the SR&T effort is to use the research staffs of the National Wind Technology Center (NWTC) and Sandia National Laboratories (SNL) to perform wind technology-specific research targeted to help industry improve the performance of components and fully integrated turbine systems. To that end, program researchers work closely with industry to define and prioritize those research activities that address their specific long and short term requirements. On occasion, program researchers may also contract with universities and other research organizations for SR&T efforts.

A Wind Turbine Pathways Analysis is used to guide the SR&T strategy, to identify areas of potential technology improvement and the specific research efforts required to achieve them. The Pathways analysis was introduced, in conjunction with annual COE tracking, in Section 5.1.2, and its application to SR&T efforts is further described below. The research and support activities are reviewed annually as part of the wind program peer review processes. Research that provides no direct link to achieving technology improvements is not pursued.

NWTC and SNL staff provide extensive design review, analysis and testing support for a broad array of industry activities including systems analyses, component blade and drive train tests in NWTC facilities, as well as validation of turbine prototypes in the field. These activities are closely coupled and directly assist industry in achieving design goals with hardware that will meet international design certification standards. These support activities are performed under the auspices of Cooperative Research and Development Agreements (CRADA) or as part of development subcontracts with industry.

Performance Measures

The success of the SR&T subkey activity, and progress in meeting its objectives, will ultimately be reflected in the progress made toward the LWST and DWT COE targets. Every research effort under SR&T has been linked to meeting these cost goals. As described in Section 3.4.1, the program has identified a set of Technology Improvement Opportunities (TIOs) that are expected to contribute to the lowering of the costs of large wind technology in Class 4 regions. Progress in realizing the benefits of those cost reduction opportunities will come from several of the program's subkey activities. In a similar manner, SR&T efforts will support the achievement of DWT goals.

ch Portfolio

Enabling Research

- Advanced Rotor Development
  - Blade development
  - Aeroacoustics research and testing
- Site-Specific Design
  - Inflow characterization
  - Design load specification
- Generator, Drive Train and Power Electronics
- Systems and Controls
  - System design tools
  - Controls design and validation

Design Review and Analysis

- LWST Public-Private Partnerships
- DWT Public-Private Partnerships

- Structural Testing
- Dynamometer Testing
- Field Testing

5.3.4 Research Activities

The program's portfolio of SR&T projects supports the cost reduction goals of the LWST and DWT subkey activities. Table 3 outlines the SR&T research portfolio.

Enabling Research

Taking turbine designs to the limit of cost and performance will require advances in several research disciplines. While some of the near-term cost of energy reductions may be possible, based on current levels of technology (e.g., tall towers), others will require investment in fundamental research to be successful.

Enabling Research activities, which support the LWST and DWT programs' goals, fall within four major topic areas: Advanced Rotor Development; Site-Specific Design;

Generator, Drive Train and Power Electronics Efficiency Improvements; and Systems and Controls.

Advanced Rotor Development – The rotor of a wind turbine is a completely unique component. The rotor's blades control all the energy capture and almost all the loads, and are therefore a primary target of advanced rotor, enabling research efforts. The challenge to be met by rotor development efforts is to create the scientific knowledge base and engineering tools to enable blade designers to achieve optimum performance at the lowest possible cost, using new materials, improved manufacturing processes, and enhanced design tools. This work will assist the industry in meeting the LWST and DWT goals by stretching rotors to greater swept area in previously un-economic wind regimes.

Advanced rotor development work can be segmented into three subtask areas:

1) Blade development
2) Aerodynamic code development and validation
3) Aeroacoustics research and testing

Each of these subtasks is an important part of program support to LWST and DWT progress, and all three will play continuing important roles over the planning period.

<u>Blade development</u>: A significant step toward the LWST and DWT goals will likely require blades that are stiffer and stronger to span the greater area, while lighter and adaptive, to reduce system loads. Beyond that, design details need to be evaluated so that the entire industry is led in the direction of efficient material usage. Finally, substantial testing, both in the laboratory and in the field, is required to validate the tools, loads, and designs, and to make sure they can be linked to the site characteristics.

The first step in blade development is gaining a basic understanding of the new materials that are likely to be used in the blades of the future. Traditional blade materials have been based on fiberglass technology typical of the boat-building industry. The next generation of machines will require longer, thinner, and equally durable blades using stiffer and stronger materials, such as carbon fibers. The program will characterize carbon's capabilities and how it interacts with the glass and other materials. The program will also explore further materials options, including resins, fiber treatments, and the effect of manufacturing processes on material properties. Full blades will be manufactured by industry partners (often at a subscale to limit research cost) to evaluate material performance in the as-manufactured state. The program will help develop sophisticated engineering tools that provide the ability to mold these materials into a working structure of minimal cost, manufacturable design, and adequate durability. The program will also continue to explore new blade shape designs that may help reduce loads and stresses, and thereby increase durability. It will then be possible to not only evaluate individual designs, but to describe how design practices should be tailored to take into account material interactions, property variability, and specified design loads.

<u>Aerodynamic code development and validation</u>: Aerodynamic code development and validation is working to overcome the fact that the current generation of aerodynamic loads/performance codes fail to adequately predict steady or unsteady loads in the near- and post-stall operating regime. Performance predictions currently rely on two

distinct approaches. The first couples 2-D airfoil performance data obtained either empirically from wind tunnel or field measurements and/or through analytic computations with momentum theory. The 3-D loads for a rotor are obtained by integrating the 2-D sectional performance along the span, adjusting the inflow and balancing the momentum flux. The benefit of this approach is an extremely fast computational time, permitting numerous iterative design permutations in almost real time. Unfortunately, details of the actual 3-D flow characteristics are ignored. In near and post-stall operation, where the flow is strongly three-dimensional, large discrepancies between actual and predicted aerodynamic performance occur. The second approach is to perform full 3-D Navier-Stokes analyses on the full rotor. Although Computational Fluid Dynamics (CFD) codes have been used extensively for helicopter and aircraft analyses for several years, the adaptation of these codes to model wind turbine rotors has only recently been attempted and is in the preliminary evaluation phase. This method will provide a detailed characterization of the underlying 3-D fluid physics driving turbine rotor performance in the near and post stall regimes for both steady and unsteady inflow conditions. However, CFD is unlikely to be used as a principal design methodology in the near future due to the extremely long computational times required for every design set point.

As model enhancements are made, the program will compare both approaches with field and wind tunnel test data in order to improve current design codes. Researchers expect that computational runs of the full 3-D codes will provide significant physical insight into the underlying separation processes in near- and post-stall operation. Based on these insights, the adaptation of new theory integrated into existing momentum and aerodynamic codes. Data that the program previously obtained from testing the highly-instrumented NREL Combined Experiment Rotor (CER) in the NASA-Ames 80x120 wind tunnel will be used to validate CFD results, theory, and improvements to the existing design codes. By empirically “tuning” the resultant aerodynamic codes, the limitations and performance errors derived from 2-D flow assumptions for a strongly 3-D turbine rotor application can be overcome without significant impacts in code run times. Results will enable more efficient design of both LWST and DWT rotors.

<u>Aeroacoustic Research and Testing</u>: Turbine noise can be caused by rotor speed, blade shape, tower shadow, and other factors. The program is sponsoring both wind tunnel and field tests to develop a semi-empirical noise prediction code that will be useable by LWST and DWT manufacturers to ensure that new rotor designs and full systems have acceptable noise signatures. High-growth domestic markets for small wind turbines will demand quieter rotors, especially when turbines are sited in residential neighborhoods. Small turbines operate at high rotational speeds and tend to spin even if they are furled (pointed out of the wind). Aeroacoustics research activities will be conducted to explore how to reduce noise produced by distributed wind turbines in a variety of wind regimes, and to develop a noise standard with industry participants that can be used for the growing domestic DWT market. This research will support the DWT and LWST public-private partnerships, both directly in working with industry and indirectly in providing necessary underlying research.

In the longer term, program researchers will work to develop physics-based aeroacoustics codes for both design and problem solving applications. These will enable more-slender blades and higher tip speeds, enhancing both cost and performance of future designs.

In summary, the rotor development activity under SR&T is closely tied to the LWST and DWT component development public-private partnerships, and will be an important contributor to expected reductions in COE. Program researchers are providing support in material analysis, blade design and analysis, and blade manufacturing. Future activities will use a cyclical approach whereby sub-scale blades and subcomponents using advanced materials and shapes are designed, built, and tested. Testing will include non-destructive approaches that can determine failure initiation and internal responses. Program researchers will enhance fatigue, material failure, and reliability analysis capabilities. In the longer term, research is expected to lead to small, integrated smart actuation devices for load alleviation and performance enhancement.

Site Specific Design – Future wind energy installations will be in areas of significantly different wind resource potential and roughness. Installations of onshore turbines will need to move into areas of lower resource, using taller towers and longer blades to harvest the more rarified energy. To continue to design for loads characteristic of more-energetic sites would drive up the cost unnecessarily and limit wind's cost-effectiveness in other areas. The benefits of designing large installations (100 MW or more) for specific site conditions are substantial. The nature of atmospheric loading at increasing heights will be assessed and documented. Blade designs, including aerodynamic geometry, controls, and structural details, need to be tuned to the energy capture requirements and durability suitable for low energy and lightly loaded sites. Every structural strength requirement throughout the system is based on the expected maximum event and turbulence at the site.

The offshore installations will operate in a very different environment, over a wide range of energy densities. These turbines must be designed knowing, in detail, the nature of the offshore winds (higher energy, lower turbulence) and the effects of wave and current loadings at the base. Existing approaches to design specification are not capable of providing a complete designation of such site design conditions.

This subtask, therefore, covers two areas. The first is the development of systematic methods for specifying specific site energy and load conditions. The other area is to conduct the field measurements that validate the methods, and to work in public-private partnerships to collect the site-specific information in important regions of the country, both onshore and offshore.

<u>Inflow Characterization:</u> A significantly better understanding of the wind resource and the nature of inflow and its impact on turbine performance and reliability must be achieved. A clear understanding of the nocturnal jets encountered at sites in the Great Plains is critical. (The nocturnal jet is a poorly understood phenomenon that occurs at night as cooling allows high level higher elevation high velocity winds to dip close to the earth's surface, creating violently turbulent wind regimes.) New components and architectures, which reduce structural loads while increasing performance and energy output when operating in these inflow regimes, must be explored. Design and performance codes must continually improve if LWST and DWT technology innovation is to be sustained.

<u>Design Load Specification:</u> The inherent uncertainties of site conditions, turbulent winds, extreme events, and component strength must all be accounted for in a manner that does not require overly conservative design margins. International standards

have traditionally specified safety factors when operating in these inflow regimes for environments intended to envelop the worst-case situation over broadly defined site classes. As turbines are routinely designed for specific sites, where these standard load cases can be reduced and tuned to site-specific conditions, the ability to estimate and account for individual design uncertainties will become a necessity. Not only will site-specific design margins be needed to avoid a catastrophic loss of a wind plant, but increasingly sophisticated financial institutions will require it for due-diligence before investing in large installations. Methods of estimating and designing to site-specific environments with uncertainty-based design margins will be established and integrated into standard design practices.

Generator, Drive Train and Power Electronics Efficiency Improvements - The generator, gearbox and power converter represent roughly 25% of the installed capital cost of a modern wind turbine. Generators have historically been based on wound rotors or squirrel cage induction designs, but such generator designs may not be the ideal design for wind turbines of the future. The drive train is becoming a major driving factor in machine design because its weight and size affect other wind turbine configuration and erection factors, such as tower size and crane rating. Variable speed wind turbine designs are highly dependent on the efficiency and mode of operation of the power converter that changes variable-frequency AC from the generator to fixed-frequency AC that is properly conditioned for injection into the electrical grid. Conversion efficiency is highly important in these designs.

Future designs of generators and power converters must be specialized and tailored to wind turbine operation because wind turbines operate the largest percentage of their time at less than rated power. The use of permanent magnet generators that are more compact and have higher flux densities will be important for future designs, as will power converters and generators that allow variable speed operation and have higher efficiencies at below-rated power. Of further importance is reliability of all components, since the generator and power converter are key points of failure in the total system. This task will explore key enabling research areas that will contribute to LWST public/private partnership improvements in converter and generator designs, focusing on generator and converter architecture, controls and reliability.

Systems and Controls – Systems and controls research is focused on a rapidly advancing area of technological innovation that offers significant potential advantage in reducing the cost of wind-generated energy. New innovative strategies are being applied to the way that wind turbine components are moved or controlled. This includes control of conventional turbine components (such as blade pitching), new components (such as twist-coupled blades), and advanced devices (such as micro-tabs). The control strategies have to be designed to meet two seemingly conflicting goals – to increase energy capture, yet reduce turbine structural loading.

LWST and DWT machines of the future will be dynamically active and must be carefully designed to mitigate unwanted structural dynamic loads and responses. New innovative rotor control strategies will be developed to mitigate the imparting of unwanted aerodynamic loads into the turbine structure. Studies indicate that low wind speed technology (LWST) goals can be met if wind energy technology moves toward large slender turbines placed on tall towers. Designing these large structures to be long lasting and fatigue-resistant at minimal cost is a difficult task. The chances of wind turbines experiencing unwanted dynamic responses and instabilities increase with height and flexibility. In addition, loads due to wind fluctuations will likely increase as rotors are placed at greater heights above ground where there is increased risk of coherent turbulence. These new machines must therefore be very carefully designed to mitigate unwanted structural dynamic loads and responses. While the rotor itself can be made more cost effective through innovative approaches to control, the entire wind turbine system is the expected beneficiary, as loads are reduced everywhere on the structure.

Recent advances in three major areas of technology are being combined and applied to provide new control strategies. First, ongoing evolution of wind turbine modeling capabilities within the Wind Program enable complex structural dynamic responses to be more accurately simulated and predicted. Second, there have been major recent developments in “state-space” control methods (and associated computer software algorithm development tools). These methods can be utilized in control paradigms to provide promising load-mitigating control strategies tailored to wind turbine technology. Third, improvements in computer hardware technology now enable data rates and control algorithm execution speeds at levels needed to successfully combine and apply the two capabilities described above. Application of the resulting control strategies, coupled with new components and advanced devices from LWST and DWT efforts, will enable turbines to be operated and controlled in innovative ways. Studies indicate that successful development of theses innovative control concepts are a major contributing factor in meeting the public/private partnership COE goals.

The program has a suite of advanced codes that will be used for modeling wind turbines of arbitrary complexity and extracting state-space matrices for turbine or controls design. Program researchers also have an extended range of analysis capabilities not previously available, e.g., operating modes computation, trim, nonlinear controls simulation, and aeroelastic stability analysis. In the short term, work will be undertaken to enhance the integrated system capability of these codes by introducing two new features: a) composite blade dynamic modeling capability and b) multivariable-controls-design-specific interface. In the future, this will be applied to the modeling of two wind turbines: a 3.6 MW wind turbine and a conceptual offshore wind turbine.

The importance of understanding DWT performance has been identified in previous Wind Program activities. However, many issues remain poorly understood when it comes to the specific behavior of small wind turbines, such as furling behavior, blade loads, and the effect of furling on turbine performance. Small wind turbine manufacturers have historically relied on variable geometry testing approaches to design for furling, tail boom lengths and tail sizes, and other related small wind turbine design parameters. It is generally agreed among small wind turbine experts that modeling small turbine furling from an aerodynamic perspective with today’s tools has a high degree of uncertainly, due, in part, to a lack of quality data on small turbine loads and operational behavior. The Small Wind Research Turbine (SWRT) was designed and built in FY 2003 and preliminary testing was conducted to start to provide data for the wind industry and wind turbine modeling community so that small turbine operation can be better understood. Over the next several years, this project will provide quality data on how small wind turbine design parameters affect turbine operation. State-of-the-art models, including ADAMS and FAST, will be constructed for the SWRT turbine and compared to the test data to further the capability of these models to predict small turbine operation.

Operations and maintenance costs have continued to drop as manufacturers and operators gain experience in manufacturing, installing, and maintaining wind turbine plants. After the low hanging fruit of improper component selection, inadequate maintenance practices, and poor installation have been harvested, it will still be necessary to drive down field maintenance costs. This is especially true as turbine size increases and the installations move offshore. Not only do the site conditions change – low level jets, tower wave, loading and corrosive wave environments – but the cost of each maintenance interaction becomes prohibitive. Methods for health monitoring and preventive maintenance will be created to mitigate the effects of increasingly more difficult operations.

Design Review and Analysis

As the Wind Program invests in the development of new technology through cost-shared contracts with industry under the LWST and DWT subkey activities, it will also be providing oversight and technical support to those activities. The Design Review and Analysis (DR&A) effort provides a means whereby NREL and Sandia staff provide specialized expertise to the industry-led activities. It also provides support to the necessary proposal evaluation process. This support and oversight not only assists industry, but also protects the Wind Program's investment in these partnerships and enhances their chance of success. DR&A services are an integral part of the phased subcontract structure for LWST and DWT turbine development activities, and are provided as support functions at the request of industrial partners.

Testing Support

An important part of the development of advanced turbines is computer modeling and dynamic simulation. However, validating and improving these models is very difficult because the models cannot always simulate true inflow, turbine response or control performance. To fill this gap, it is necessary to perform extensive, detailed field-testing and to utilize the data collected to improve both the control algorithms themselves and the simulation codes from which they were designed. Tests are conducted on operational turbines in the field, and on a wide range of full-scale turbine components in specialized testing laboratories.

Structural Testing - The NWTC structural test facility has been operating since 1990. This facility has been used primarily for testing full-scale wind turbine blades for Wind Program subcontractors and wind industry partners. The present capabilities include fatigue testing, ultimate static strength testing and several non-destructive techniques, such as photo-elastic stress visualization, thermographic stress visualization, and acoustic emissions. Rapid growth in the size of wind turbines has strained the capacity of the existing structural test facility to its limit. The facility is unable to test the next generation of blades. Many of the proposed LWST projects, as well as current industry development, exceed the size and load capacity of the existing facility. Multiple large blade failures on field-deployed turbines – weighing over 10-tons each – would not only be dangerous, but would undermine industry credibility and hinder reaching DOE's COE objectives.

During the planning period, the Wind Program expects to build a 70-meter blade facility. This new facility will be constructed at the NWTC and will be co-located with the existing facility. The new facility will have the capacity to test multiple blades simultaneously. Both the current test facility and the 70-meter facility will be available for turbine testing into the next decade, and will be essential in meeting the LWST goals.

Dynamometer Testing - The 2.5 MW Dynamometer and Spin Test Facility at the NWTC is a test bed dedicated to the testing of wind turbine drive trains, drive train components, and power systems. The project began in 1995 as a result of wind industry input that a facility of this type was needed. The facility was completed in August 1999. The NWTC staff currently conducts tests such as gearbox fatigue, wind turbine control simulations, transient operation, generator and power system component efficiency and performance for the advancement of the U.S. Wind Energy Industry. Previously, the only way to verify operating integrity throughout the turbine's full load envelope was to test a field prototype under severe conditions. This NWTC facility provides improved methods for full-system testing of wind turbine systems to identify critical integration issues before field deployment. This unique facility gives the U.S. industry an edge over strong European competition.

The Wind Program plans to maintain its leadership role in wind turbine drive train testing and meet the needs of the emerging multi-megawatt industry with a two-pronged approach. First, the existing 2.5-MW facility will be fully supported to operate at maximum capacity into the foreseeable future, meeting the needs of current turbines in the 1 to 2-MW size range. Secondly, a new 5-7 MW dynamometer facility will be constructed to test the upcoming multi-megawatt wind turbine generation. Tests will be performed to verify gearbox design conditions, evaluate new low-speed permanent-magnet direct-drive generator technology, and test innovative power electronic devices proposed under the LWST project.

Field Testing - Field testing supports a wide range of LWST and DWT activities. Such testing is typically conducted on full-scale turbines installed in the field, although it is also done on components and subsystem test articles. Field testing necessitates installation of sensors and transducers (e.g. strain gages, accelerometers) used to quantify loads on operating turbine structural components, noise emissions, output of electrical systems, and meteorological inflow conditions. The test devices are connected to special ruggedized computer-based data acquisition systems. The large quantities of resulting data often require specialized processing and analysis to extract required information. Field tests measure turbine loads, acoustic emissions, power production, and power quality. Resulting loads data are essential in verifying computer simulation models of wind turbine configurations. Field test data are especially important for assessing the viability of new, innovative turbine configurations, since models of such configurations often need tuning with test data to establish necessary confidence levels.

Accredited turbine field data are essential inputs to design evaluations required to support certification and due-diligence activities. For wind turbines to be successful in the marketplace, both domestically and internationally, they must meet international standards for reliability, and must ultimately the certifiable by standards bodies. The collection of reliability data in the field helps manufacturers identify evolutionary technical improvements.

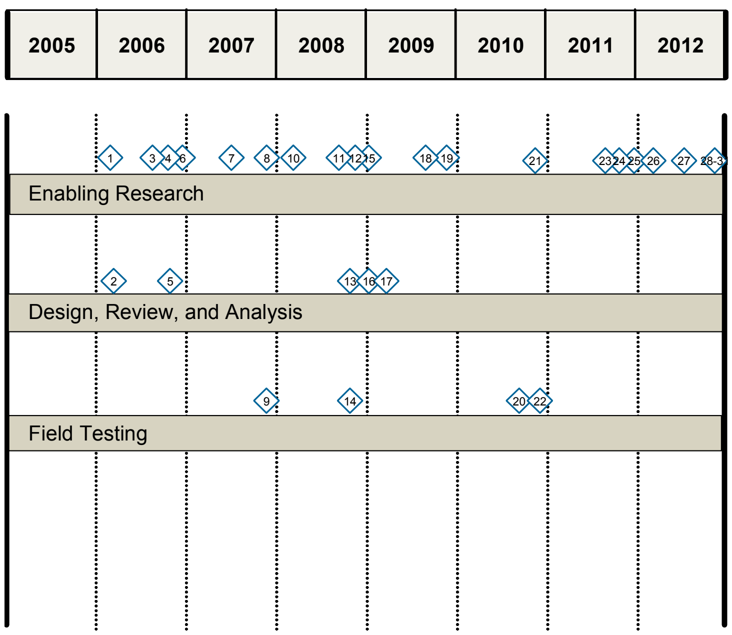
Future testing activities that will improve the reliability and durability of wind turbines include:

- Developing improved life-cycle testing protocols and analytical methods;
- Developing a better understanding of design load characterization for enhanced reliability, durability and longevity;
- Performing durability and reliability testing for environmental extremes; and
- Identifying design elements necessary to achieve 20+ year operating life.

5.3.5 Milestones

Milestones for the Supporting Research and Testing subkey activity provide planning guidance and a means by which progress can be tracked.

Supporting Research and Testing



ilestones

1. Complete field-testing of carbon-hybrid research blade
2. Complete final Phase II component design reviews
3. Document load implications of Lamar LIST/LLJ test
4. Complete field-testing of twist-coupled research blade
5. Complete final Phase II systems design reviews
6. Complete development of engineering inflow model for Great Plains
7. Formulate turbine blade post-stall model and validate with UAE data
8. Publish LWST Airfoil Database from Wind Tunnel Tests
9. Complete field testing of Phase II components
10. Conduct Computational Aeroacoustic Codes Workshop and Training
11. Publish Field Test Code Validation Results
12. Complete Advanced Control Testing and Evaluation for 2- and 3-bladed Rotors
13. Complete final Phase III concept design reviews
14. Complete field testing of Phase I systems
15. Complete Great Plains measurement campaign and data analysis
16. Complete final Phase II component design reviews
17. Complete final Phase III systems design reviews
18. Validate advanced free vortex wake code
19. Develop control models and algorithms for offshore wind turbine designs
20. Complete field testing of Phase III components
21. System Identification and Model Uncertainty Reduction
22. Complete field testing of Phase II systems
23. Test and Evaluate Advanced Controls utilizing Advanced Sensor Technology
24. Complete Offshore measurement campaign and data analysis
25. Publish Loads and Stability Tools and Guidelines
26. Embedded blade sensing and control - validate in full scale
27. Integrate inflow testing results into design standards
28. Complete validated offshore maps for U.S.
29. Integrated Aeroelastic Code Development and Verification
30. Formulate fully-coupled aeroelastic computational model and validate
31. Offshore blade validated

6.0 Technology Application

The Technology Application key activity area addresses the many non-technology barriers to the use of wind energy systems. These barriers and opportunities are different for the different size machines, as shown in Table 4.

Table 4. Wind Turbine Market Segmentation

Turbine Size Range	Applications	Barriers
Small (<10 kW)	Residential, off-grid	Zoning, integration into new applications
Intermediate (10 kW – 500 kW)	Wind/diesel, industrial	Power quality, control and stability, storage, zoning
Large (500 kW – 5 MW)	Grid Interconnect	Transmission access and operational im
Very Large (>5 MW)	Off-Shore Grid Interconnect	Ca frame

The Technology Application key activity encompasses three subkey activities: Systems Integration, Technology Acceptance, and Systems Engineering and Analysis. Table 5 provides the budget assumptions made in preparing the Technology Application plan. Because final program funding allocation decisions are made annually by the Department of Energy, these values are likely to be adjusted each year. They do, however, provide a general sense of anticipated funding trends, consistent with meeting the goals described in this chapter.

Table 5. Multi Year Funding P
Technology Application (mil

Key Activity	FY04	FY05	FY06	FY07		FY09	FY10	FY11	FY12
Systems Integration	3.1	3.2	3.4	4.1		4.8	5.0	5.0	5.0
Technology Acceptance	3.5	4.0	3.8	3.8		3.1	2.4	2.4	2.4
Supporting Engineering and Analysis	3.4	3.4	2.6	2.6		1.6	1.6	1.6	1.6
Total	10.0	10.6	9.8	10.5		9.5	9.0	9.0	9.0

6.1 Systems Integration

The Systems Integration subkey activity is working to facilitate the adoption of equitable grid access and operational rules for wind in all major regional wind markets, to ensure that wind's needs are considered in regional transmission planning processes, and to enhance wind's compatibility with the nation's energy needs over the long term.

6.1.1 Goal

The goal of the Systems Integration activity is: "By 2012, complete program activities addressing electric power market rules, interconnection impacts, operating strategies, and system planning needed for wind energy to compete without disadvantage to serve the Nation's energy needs."

6.1.2 Technical Challenges

The need for Wind Program activity in Systems Integration arises because wind is a new power technology with natural variability. In the short term, wind presents challenges to traditional power-system planning and operating procedures. Hence, wind is met by a natural resistance in the electric power sector. Publicly funded activity is needed to overcome this reluctance if wind's public benefits are to be realized.

Concurrently, as wind energy capacity increases in the nation and associated interest from electric utilities and regional operating entities grows, the need for improved methods and tools for integrating wind energy into the bulk power system becomes more evident. The electric industry is, itself, in a challenging period characterized by changing market rules and regulatory oversight, corporate restructuring, high competition, and technological change. The integration of renewable energy, including wind energy, into its supply mix, is one of many issues the industry is grappling with before it can move fully into this newer, more competitive market structure. At the same time, the installed capacity of wind power has increased steadily in the United States and throughout the world. Research and development efforts by the industry and government have made wind energy competitive with that of traditional fossil-fuel generation in many locations. With the aid of various state policies and the emerging green power market, thousands of megawatts of wind power plants, of various sizes, have been built in the United States over the past few years. This trend is expected to continue in light of increasing environmental concerns, hydropower shortages, and swings in natural gas prices.

As a result of these developments, more utilities are seriously evaluating wind power. However, these utilities are also concerned about possible impacts on system operations when a large amount of wind power is introduced into the electric power system. Their concern is despite the fact that, by the end of 2003, some 6,400 MW of wind generating capacity had been installed in the United States, 14,600 MW in Germany, and 40,000 MW worldwide. Their concerns are also despite the fact that wind energy and cogeneration sometimes total as much as 100 percent of instantaneous generation in Denmark. Utility decision makers, state regulators and investment bankers are unfamiliar with wind, and, therefore, overly cautious in their view of wind power as a utility generation asset. Principal among their concerns are potential system effects due to the current limitations in wind forecasting and the potential electrical system stability and dispatch implications. Their concerns, if not adequately addressed, could significantly limit the development potential of wind power in this country.

Since the inception of the program in the early 1970s, wind energy has generally been considered as a fuel-saver. That is, the primary economic and environmental benefit of wind energy is to reduce fuel consumption by other generators. Wind energy also displaces related operating and maintenance efforts and can enhance system reliability at times of system peak, on a statistical basis. However, as a consequence of wind's variability, utility operators often mistakenly assume that the full output of a wind plant can be lost at any second, and thus capacity for the full wind farm output must be on reserve. Wind's relatively low capacity factor (25 to 50 percent) suggests that for transmission service, which is usually priced in terms of $/MW-year, wind would have difficulty competing with a baseload option. In addition, renewable sources like wind are often located away from load centers, increasing relative transmission requirements compared to conventional sources. Another aspect of variability that disadvantages wind energy is that scheduling generation service, normally required one day or more in advance, is difficult for wind plants because of inherent limits in the ability to forecast wind plant output 24 to 72 hours in advance. Conventional units can be turned on or off based on operator's decisions, whereas a wind project requires the wind to generate power.

In the early days of the wind program, it was generally accepted that only a small fraction of energy on a power system could come from wind plants. A rule of thumb was five percent. Later, more detailed studies that looked at explicit representations of risk, wind power and impact on utility operation suggested that the five percent figure was only a conservative limit and that greater penetration could be achieved if power system operation were changed to accommodate wind energy. However, even at the five percent level, there is sufficient regulating capacity in typical utilities to compensate for the total loss of a typical wind plant. As instantaneous wind energy penetration increases on a system, the units operating on economic dispatch are backed off, i.e. fuel is saved, while those units that compensate on a minute by minute basis for imbalances between load, generation and exports (units on regulation) must vary their operation more frequently. Recent data suggests that the impact of typical wind projects on the need for regulation is small. In some regions, the regulation service is provided at an additional cost by the wind plant operator. In other regions, regulation is provided as a service by the power system or the regional transmission organization, with costs paid by load-serving entities, not by the wind generator.

While the wind industry has experienced constant growth over the past decade, to enable the technology to reach its full potential, DOE researchers are exploring innovative applications like offshore deepwater development, the use of wind energy to clean and move water, and developing new technologies that will enable wind energy to work in synergy with other energy technologies such as hydropower and hydrogen.

For offshore turbines in very shallow water (5–12 m), European turbine manufacturers have adopted conventional land-based turbine designs and placed them on concrete bases, steel mono-piles, or truss support structures and anchored them to the seabed.

An offshore substation boosts the collection system voltage, and a buried undersea cable carries the power to shore, where another substation provides a further voltage increase for transmission to the loads.

Although the same approach can be used for wind turbines installed off the East Coast, the wind, wave, tide, and current design conditions are thought to be more severe in the United States and less well defined than for the Baltic and North Seas. In addition, the turbine structural dynamics and fatigue loadings of offshore machines are much more complex and difficult to analyze than for turbines on land. Thus, researchers will need to conduct supporting R&D to validate the turbine designs and reduce the risks. Offshore projects must be larger in terms of both turbine size and project scale to support the costs of the added turbine seabed support structures and cabling. These factors will tend to make financing offshore projects commensurately more difficult until offshore wind technology has proven its viability and profitability to investors.

While fluctuating power levels and transmission constraints may hamper ready adoption of wind energy to utility grids, fluctuating regional water resources, growing obligations and market pressures on water uses (need for flood controls, environmental issues, and recreation) are just a few constraints faced by the hydropower industry. Most experts agree that the value of wind and hydropower could be mutually enhanced by working together. For example, variations in power delivery levels caused by natural wind speed changes could be damped or eliminated. Hydro facilities might act as “batteries” for wind power by storing water during high wind periods, and increasing output when wind power goes down. Similarly, periods of low water resources or policy pressures on water use can be mitigated by using wind to generate power normally generated by the hydropower systems.

In addition to exploring the opportunities for wind and hydropower to work together to produce a stable supply of electricity, researchers are examining ways wind can help resolve conflicts that surround fresh water uses. Other potential wind/water applications include the use of wind energy to clean water used for oil and gas exploration processes, provide power for municipal wastewater treatment, and provide power for irrigation systems.

6.1.3 Technical Approach

Strategy

The Systems Integration subkey activity strategy, as shown in Figure 13, is to assist regional electric system planning and operations personnel to make informed decisions about the integration of wind energy into their systems. Three primary targets have been identified: 1) Technology Characterization and Data Collection; 2) Tools and Methods Development; and 3) Application and Implementation. Program personnel will work with organizations such as Independent System Operators, Regional Transmission Organizations, the Federal Energy Regulatory Commission, and state and local utility planners to have wind considered in their deliberations and rulemaking proceedings in a fair and equitable manner. The program coordinates closely with the American Wind Energy Association, which is particularly proactive in this area due to its potentially crippling implications for future wind development. As future markets and applications are considered, the program will integrate their needs into the activities conducted under the three target areas described in Figure 13.

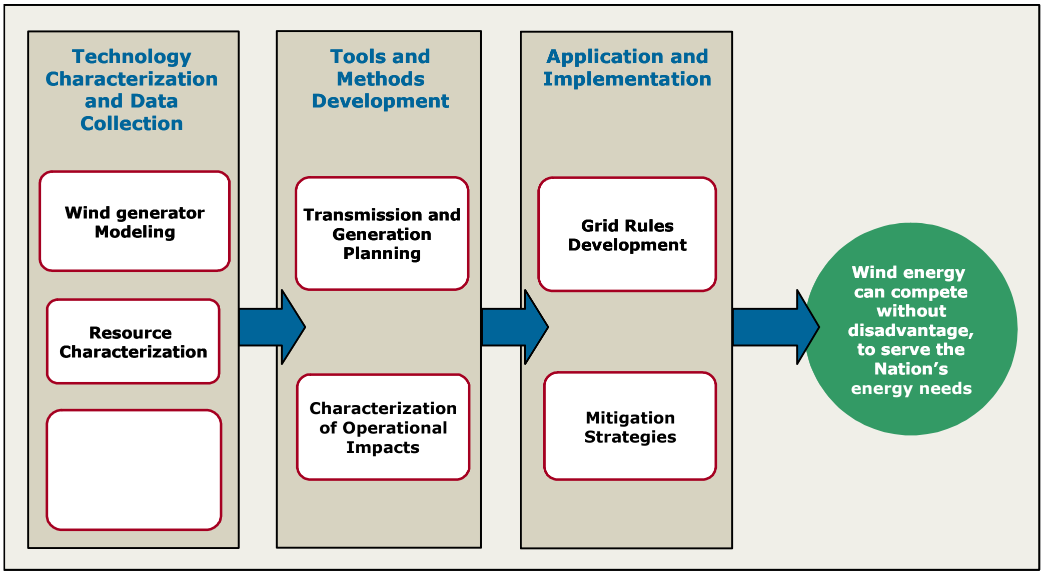


Figure 13. Systems Integration Research Plan

Outreach to stakeholders is a key element of the Program's strategy in Systems Integration. This provides ongoing two-way communication to (a) ensure a thorough understanding within the Program of major needs and issues relative to wind's integration into the nation's energy infrastructure; (b) define and refine Program activities in response to these needs; (c) deliver relevant Program products and expertise to those who can use them; and (d) increase key stakeholders' awareness of wind power's actual – not suspected – integration impacts and its evolving maturity. This outreach is conducted through a variety of avenues, including: participation in relevant projects with electric-power sector representatives, either as funders, technical consultants, reviewers, or a combination of these; participation in meetings where relevant issues are discussed or where power-system rules are being deliberated; support of and participation in relevant activities of key stakeholder groups such as the Utility Wind Interest Group and the National Wind Coordinating Committee; and interactions with the American Wind Energy Association and members of the wind industry. The Program is also engaging a Systems Integration expert group, discussed below, that will provide additional outreach across all of these avenues.

A regional focus has been adopted because of the emerging importance of regional planning entities in electric system planning and market operation. Because wind program personnel will not ultimately be responsible for the decision making of these organizations, the program's strategy is to define and complete activities, on a region-by-region basis, that provide system operators, planners, and relevant decisionmakers with the information and tools needed for equitable treatment of wind power in the energy marketplace.

Needs will vary from region to region. In setting priorities for activities to support, the Program considers factors such as: regional wind-resource potential; degree of acceptance of or hostility toward wind power, as indicated by existing practices and attitudes; presence or absence of regional partners to work with; degree of regional funding support available; likely impact relative to program resources required; and potential for expansion of wind into promising new locations or new energy markets. The response to these factors will vary in specific situations. For example, a region with excellent wind potential may already have substantial activity underway with state or local funding to facilitate wind integration. In this situation, Program support may offer only marginal value so should be directed elsewhere where needs are greater. On the other hand, in some cases the Program might provide critical consultant support or technical review at minimal cost that substantially increases the validity and acceptance of the regional work. In such a case, even though committed regional resources are already large, the Program would provide its support.

The Wind Program believes that a major public good is served by providing unbiased data about operation of wind energy in electric power systems. Wind energy saves fuel and O&M cost, provides jobs, and provides an alternative source of energy, thereby providing national security benefits. Electric utilities, State and Federal regulators, and the general public receive benefits from these activities that would not be provided by the private sector alone. The program will sponsor research and collect operational data when a major public benefit exists. In other cases, the principal responsibility may lie with wind turbine manufacturers and power system operators in developing simulation models for wind turbines. In such cases the program may still play a facilitating role. In still other cases, primary responsibilities must lie with regional stakeholders, power system operators and regional regulators in developing transmission plans to accommodate wind, while the program will provide supporting technical data and encourage fair treatment of wind.

Performance Measures

Progress in this subkey activity will be measured by examining the sufficiency of program accomplishments in each region of the country. Under Systems Integration, the program will provide technical support in electric power market rulemaking, the assessment of interconnection impacts, the development of tools to guide operating strategies, and the conduct of transmission system planning. When the program efforts in these four areas are complete, the program's efforts will be judged to have been successful. The completion of program activities is not predicated upon acceptance of, or implementation by, the stakeholders of any of these program outputs, since the program can only make support and tools available for use, but cannot directly influence whether they are adopted by regional planners and operators. However, the wind industry and many public-interest stakeholders will be highly motivated to encourage the adoption of program results. Hence the probability of acceptance and implementation is high.

Figure 14 shows the process that will be used to assess this subkey activity's progress in reaching its goal. Regional and national systems integration experts will be asked to periodically assess the progress and status of each region in addressing the four areas outlined in the Systems Integration goal. On an annual basis, these experts and the Program will judge the extent to which program efforts are complete. This group of experts will include individuals intimately familiar with regional electric-power-sector issues, as well as other relevant regional stakeholders. Based on informed perspectives from each region, the group will consider the relative importance of program efforts in these regions, recognizing that some regions have greater wind potential than others. These assessments will be used by Program management to guide and refine planning for the program's systems integration activities in each region.

6.1.4 Research Activities

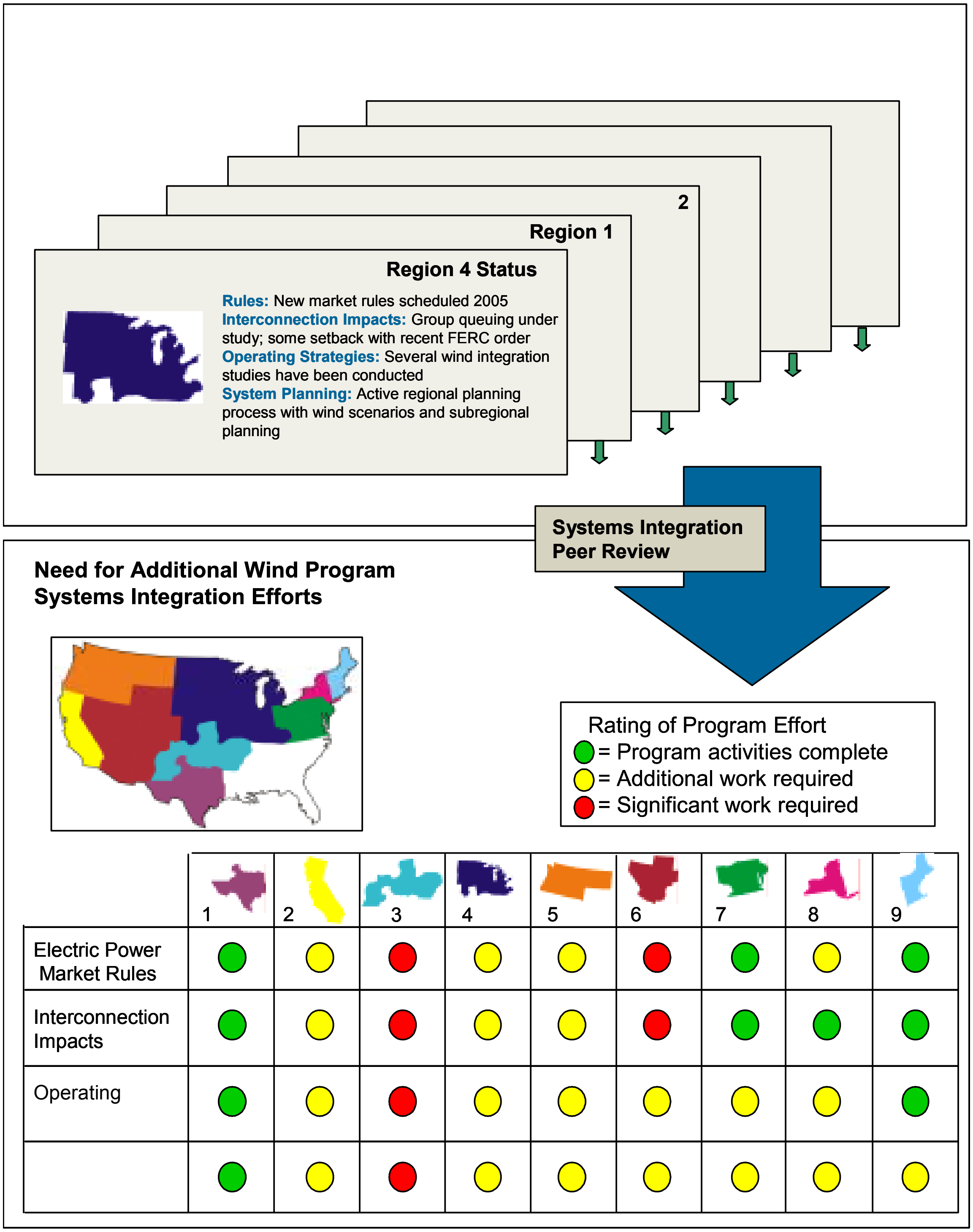


Figure 14. Regional Assessment of Systems Integration Progress and Peer Assessment of Need for Continued Program Role

Wind power is a unique source of electricity. The natural variability of the wind resource raises concerns about how wind can be integrated into routine grid operations, particularly with regard to the effects of wind on regulation, load following, scheduling, line voltage, and reserves. A lack of understanding of these areas is inhibiting market acceptance and hindering increases in the amounts of wind power. System costs associated with variability are only now being analyzed. The impact of higher penetration, and potential mitigation measures, are not currently being approached systematically. In addition, current transmission tariffs and grid operational procedures do not recognize wind characteristics, and, therefore, often unintentionally create deployment barriers. Despite these challenges, grid reform associated with FERC rules and RTO development presents an opportunity to work toward removing barriers. Various utilities and the Utility Wind Interest Group (UWIG) have taken lead positions in analyzing these issues; and the Wind Program is establishing a framework, in concert with the electric-power industry, to ensure technical accuracy and advancement of methods.

Technology Characterization and Data Collection

Wind Generator Modeling – The program is working with the wind industry to provide utilities and grid operation organizations with better wind generator electrical models to evaluate interconnection and system impacts of proposed wind farms. Valid wind-turbine and wind-plant models are essential for evaluating wind-plant impacts on electric system stability. Without these, the grid evaluations will use generic induction generator parameters, and the amounts of wind capacity that will be allowed access to transmission interconnection will likely be unnecessarily low. By using non-wind-specific models, these organizations will not capture the advantages of variable speed power electronics, including their ability to provide VARs and their fault ride-through capability.

Current efforts in this area include support for ERCOT's development of an initial set of detailed software models of the different classes of commercial wind turbines. Although somewhat rudimentary, these models represent an important beginning of better wind turbine representation. The program will support future validation and training efforts, and improvement of these models as the validation process proceeds. An important goal of this effort is to encourage the use of these models in other regions.

The program has examined, with SCE, transmission limitations in the Tehachapi region of California, to better understand the effects that the current installations of induction turbines are having on the operational stability of that region. The goal is to develop a better understanding of the interaction of wind generators with the local grid operation, and to identify ways to mitigate the specific operational issues confronting that region.

Wind Farm Data Monitoring – The principal concern by electric utilities unfamiliar with wind energy is that the plant output can suddenly fall to zero. Data on the second-by-second power fluctuations from commercial wind farms has not historically been available. However, the program's ongoing cooperation with FPL Energy at Lake Benton II (MN) and Storm Lake (IA) has begun to provide excellent data to fill this need. Without long-term data sets from various wind resource regimes, evaluation of the grid impacts of variability cannot be performed. The data gathering effort has recently been expanded to include plants in Texas, the Northwest, and California. The data for the Northwest is being collected in cooperation with Bonneville Power Administration. Over the coming years, locations in Colorado, Wyoming, and other states will be added. The program will publish statistical data reports that will become a public reference for the future development of wind farm impact models.

Resource Characterization – The program will work to provide representations of the wind resource, including seasonal, diurnal and hourly shapes, where possible, to allow models to better characterize the potential benefits and impacts that wind can have on system operation, and to assess availability of transmission. These wind profiles are essential for evaluation of wind-plant contributions to overall system reliability. Many of the same time series data bases used in validation of recent state maps can provide a basis for this new effort. The data collected in the wind farm modeling effort will also contribute to resource characterization. Over the next few years, the program will expand the resource characterization effort to include more sites, with different characteristics, and will ensure that this data meets the needs of the wind forecasting work described later in this section.

Tools and Methods Development

Grid Operational Impact Analysis – The wind program will address the variable, normally uncontrollable nature of wind power plant output, and the additional needs that its operation imposes on the overall grid. This work is essential to allay fears about backup generation requirements and excessive increases in ancillary services costs. At present, the generation and transmission operational impacts that occur due to wind variability are not well quantified. At lower grid penetrations, these impacts have not generally been an issue. This research will include efforts to quantify and fairly allocate impacts in both an engineering and cost sense. Analysis methods are at an early stage of development. Without realistic analysis and cost allocation, utilities often tend to overestimate wind's operational costs, resulting in the undervaluing of wind power in the system. Unrealistically high ancillary cost evaluations will result in lower wind deployment rates.

A recent study of the Xcel grid indicated that 300 MW of wind would impose an additional operating cost of around 0.18 cents/kWh of wind energy produced. This level represents a penetration of about 4% of the Xcel grid capacity. A more recent study of wind in the Xcel system, completed in September 2004, evaluated the expected operating-cost impacts of a 15% penetration level. Results indicate additional operating costs of about 0.46 cents/kWh of wind energy. And in an earlier study, PacifiCorp has estimated an additional cost of 0.5-0.6 cents/kWh for integrating 2000 MW of wind, or nearly 20% of its capacity, into its grid. For all of these studies, and other similar work, the Program has provided critical input data, consultant support and detailed technical review. In addition, the Program plans to sponsor the development of methods for integrating these results into utility and regional operating assessments.

The program also sponsors an outreach activity to work toward the adoption of the rules and techniques developed in the analytical portions of this effort. This outreach function is essential if the benefits from this technical activity are to be realized.

Transmission and Generation Planning – Continued growth in electric loads results in the need to plan for and install new generators and transmission lines. Wind generation is a relatively new wholesale power source, so planning organizations do not generally include wind in their planning methods. Future utility resource plans and regional planning efforts should include wind stakeholders in the overall process.

Traditional transmission planning in the nation tends to be reactive, rather than proactive. Planners respond to requests for interconnection of new generators individually, rather than estimating future regional needs in an integrated fashion. The program, in part through support of transmission work of the National Wind Coordinating Committee, will encourage and facilitate such proactive planning. Progress on this front will provide broad benefits to the entire power system and to the general public, and will also enable expanded use of wind power.

Characterizations of potential wind resource locations and power delivery profiles are critical to the accurate assessment of potential transmission line upgrades or expansions. In addition, the reliability characteristics (capacity credit) resulting from wind and utility load temporal profile matches affect the valuation of wind in planning processes. Most of the foregoing can be handled by existing utility practices, as long as the required data is available.

One problem for wind developers is that existing practice for interconnection requires the same level of interconnection studies for a 25 MW wind plant as for a 1000 MW coal-steam plant. Further, as each study is completed, the dynamics of the network often change, rendering earlier studies invalid. This becomes an expensive, time consuming hurdle for most wind projects. What is needed in each region for cost-effective deployment of wind power is an integrated study such as the MISO/Wind-On-the-Wires/AWEA study of 10,000 MW of wind that was recently completed, or the preliminary work of this type that was done in PJM, the regional transmission organization that serves the mid-Atlantic and adjoining regions. The role of the wind program is to provide technical information and assistance where needed.

The program will continue its active participation in regional transmission planning processes. The Rocky Mountain Area Transmission Study for studying the potential of adding transmission to access coal and wind resources in the Rocky Mountain States, the New England Wind Barriers Project, and the Midwest ISO Transmission Expansion Plan (MTEP) are examples. Support for the development of reliability methods that treat wind in a non-discriminatory fashion by program staff and consultants will continue, as will program engagement in regional reliability methods development.

Application and Implementation

Grid Rules Development – As a low capacity factor, variable resource, often located far from load, wind power can be adversely impacted by the changes in wholesale market structures, organizations and rules that are setting the stage for future grid treatment of wind. Under many existing penalty-based rules, proffered in FERC Order 888 to drive good market behavior, wind is inappropriately disadvantaged. FERC's proposed order, in 2003, on Standard Market Design would be a major improvement, but that order now looks unlikely to be adopted soon because of regional concerns about roles and responsibilities. If that proves to be the case, wind energy stakeholders armed with information must be at the table in each region for both interim and future rule development processes. The methods developed in other regions must be presented and applied to specific grid rule development processes in these venues. In addition, FERC is showing interest in amending Order 888 to reflect industry and regulatory concerns over some of Order 888's provisions, including penalty-based rules that have been a large barrier to wind generators.

Without such activity, wind energy will inevitably suffer arbitrary and unsubstantiated reductions in value. This is a major challenge for the entire wind energy community, and the program is providing a critical support role.

The program is actively engaged in supporting regional processes to develop grid rules for wind. Efforts in this area include: 1) Participation in Western Electric Coordinating Council (WECC) and the aforementioned Rocky Mountain Area Transmission Initiative processes; 2) Supporting the efforts of program consultants to quantify the costs and benefits of wind integration, including regulation impact and capacity credit, into the California ISO and the Southwest Power Pool; 3) Monitoring New England RTO, PJM RTO and New York ISO processes; and 4) Working with the Western Interstate Energy Board on "A Project to Facilitate the Sharing of Wind Energy Information Across the Western Interconnection."

Offshore Wind Development – Traditionally, the great majority of the Wind Program's activities have been directed at onshore wind deployment, including the System Integration work outlined above. Over the next several years, attention to offshore wind is likely to expand in the United States – as it has in Europe – particularly in coastal regions. Offshore deployment will bring its own set of system integration issues. For example, injection of large amounts of variable power at single points of connection to transmission networks that may already be congested or severely undersized– as well as impacts of this power on operation of the power system – will require extensive analysis. It is likely that some of the Systems Integration program's attention will shift toward offshore issues over the coming years.

Operational Impacts Mitigation Strategies – As wind deployment expands, costs for the integration of wind onto the grid may increase, especially at higher penetrations. Both short and longer term mitigation of variability issues, including wind plant forecasting and control, application of energy storage and regional cooperation, could reduce additional integration costs. In the near term, efforts in this area will include examination of wind and hydropower integration opportunities. Early efforts will perform site-specific analyses and case studies for WAPA and BPA. In the longer term, efforts may include wind integration with storage, wind generation of hydrogen, and application of wind power to large, unconventional markets such as water treatment and desalination. Activities like these are essential for wind to evolve into a truly significant contributor to the nation's energy needs.

Emerging Applications

Wind and Hydropower – DOE began exploring the potential synergy between wind and hydropower resources in November 2003 when it sponsored an IEA R&D Wind Annex XI Topical Expert Meeting on the Integration of Wind and Hydropower Systems. Hosted by BPA in Portland, Oregon, the meeting drew 28 energy experts from the United States, Canada, Norway, and Sweden. The participants' presentations ranged from high-level national perspectives on wind/hydropower integration to details of specific wind/hydropower projects. The main topic was whether wind and hydropower technologies and can work together to provide a stable supply of electricity to an interconnected grid. Although no formal decision was made, the formation of an IEA wind/hydropower integration R&D annex is being seriously considered.

In the meantime, DOE has begun to analyze several specific potential and actual generation projects and full watershed basin/electric control areas. Planned work includes: 1) Upper Missouri River Basin Study – In conjunction with the Western Area Power Administration (WAPA) and the U.S. Army Corps of Engineers, the program is exploring the technical potential of integrating large amounts of wind power into the Upper Missouri River hydropower operations; 2) Bonneville Power Administration (BPA) Operating Analysis – BPA is examining the impacts and costs of integrating large amounts of wind power into their system and has created two related product offerings; 3) Grant County Public Utility District (GCPUD) Wind/Hydro Study – GCPUD, with the assistance of NREL, will be studying the potential for integrating significant wind energy into their hydro operations; and 4) Arizona Power Authority (APA) Wind/Hydro Study – APA, as a customer of Hoover Dam electricity, will be initiating a feasibility study on integrating wind into their hydropower allocation. The U.S. Bureau of Reclamation and WAPA will be collaborators in the study.

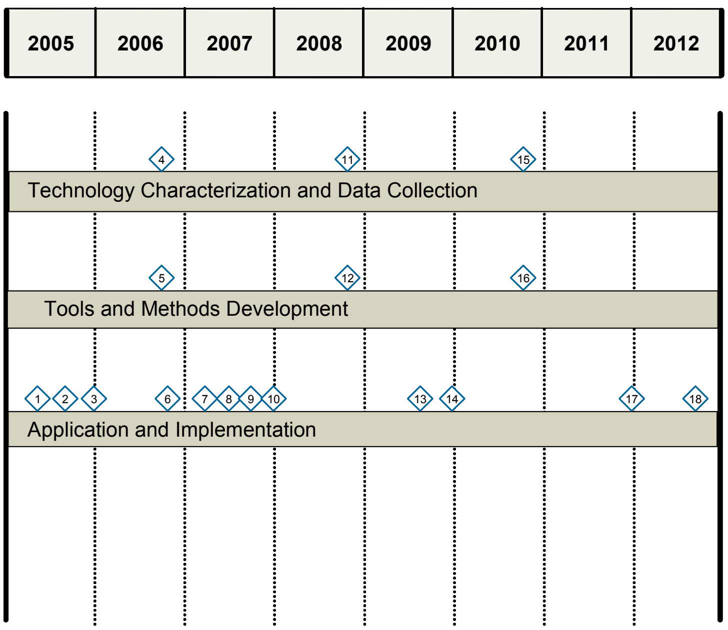
Wind and Hydrogen – Researchers are also looking at both wind and hydropower – two of the lowest cost renewable energy resources – to help produce hydrogen, another clean energy source. According to a report recently released by the National Research Council (NRC),"A transition to hydrogen as a major fuel in the next 50 years could fundamentally transform the U.S. energy system, creating opportunities to increase energy security through the use of a variety of domestic energy sources for hydrogen production while reducing environmental impacts, including atmospheric CO_2 emissions and criteria pollutants." The report recommends that DOE focus its research on distributed natural gas and wind-electrolysis to enable this transition within the next two decades.

As one of the most cost-competitive renewable energy technologies available today, wind energy has the greatest potential for producing pollution-free hydrogen. It fulfills two main motivations propelling the current push toward a hydrogen economy; reducing CO_2 emissions and reducing the need for hydrocarbon imports. In September 2003, DOE hosted a workshop to bring together stakeholders from the wind, hydropower, and electrolysis industries to explore the potential for cost-effective electrolytic production of hydrogen from wind and hydropower. Fifty-three participants, representing wind turbine manufacturers, electrolyzer manufacturers, hydropower generation facilities, utility companies, research institutes, national laboratories, trade and public interest associations, consulting research firms, and DOE, attended the workshop. The key goals were to: 1) Start a dialogue among industry stakeholders on key opportunities and potential technology synergies; 2) Review and gather industry feedback on current modeling and analysis efforts funded by DOE on the potential for co-production of electricity and hydrogen from wind and hydropower; and 3) Obtain industry input on key challenges to electrolytic production of hydrogen from wind and hydropower and the R&D activities needed to address these challenges.

The program and the participants agreed to continue and expand the dialogue on hydrogen production with a larger group while DOE considers the formation of an industry working group that will develop recommendations for future activities. NREL researchers will incorporate the recommendations they received from industry members in their modeling efforts.

Clean Water – Finally, the program began in 2004 to identify ways in which wind power could contribute to supplying and cleaning water for the U.S. The program believes that wind power could enhance regional water stocks by reducing traditional generation sources' demand for water. Thermal power generation now uses as much fresh water in the U.S. as irrigation (each use 39 percent of total), using on average 21 gallons of water to produce one kilowatt hour of electricity.

Systems Integration



Milestones

1. Promote development of consensus utility transmission planning principles
2. Complete primer for utilities on expected operational impacts of wind power
3. Complete periodic review by SI Expert Group
4. Ensure availability of efficient wind-plant electrical models for representative wind generation hardware
5. Complete and publish comprehensive summaries of wind's impacts on electric-system operation and ancillary-services costs
6. Complete high penetration study, with validation, for one RTO
7. Complete three case studies of wind forecasting value
8. Complete mitigation study for RTO studied in 2006
9. Complete comparative evaluation of capacity accreditation methods
10. Complete periodic review by SI Expert Group
11. Ensure availability of efficient wind-plant electrical models for representative wind generation hardware
12. Complete and publish comprehensive summaries of wind's impacts on electric-system operation and ancillary-services costs
13. Complete evaluation and recommendations for high-wind penetration scenarios based on production of electricity and hydrogen
14. Complete periodic review by SI Expert Group
15. Ensure availability of efficient wind-plant electrical models for representative wind generation hardware
16. Complete and publish comprehensive summaries of wind's impacts on electric-system operation and ancillary-services costs
17. Complete periodic review by SI Expert Group
18. Complete recommendations for long-range power system planning that optimizes the realization of wind power's overall benefits from a comprehensive IRP perspective

While wind energy has historically been used for water pumping and irrigation, today's wind systems could play an important role in ensuring future water supplies. Wind could be used for desalination of inland brackish or coastal sea water, to provide power needed to treat water used in oil and gas exploration processes, to provide power for municipal waste water treatment, and to meet distributed water stock pumping and irrigation needs. The program will be looking at the technical and practical aspects of these applications over the next several years.

6.1.5 Milestones

Milestones for the Systems Integration subkey activity provide planning guidance and a means by which progress can be tracked.

5.2 Technology Acceptance

The Technology Acceptance subkey activity provides information about wind energy technology and its potential benefits to the stakeholder community, to allow informed decision making and to reduce undue barriers to the use of wind power. The success of Technology Acceptance efforts in removing barriers will be key to the long-term success of LWST and DWT technologies and to emerging applications of wind technology in the energy marketplace.

5.2.1 Goal

The current (FY 2004) goal of the Technology Acceptance subkey activity is that "By 2010, at least 100 MW will be installed in 30 states." In FY 2005, the Wind Program will develop - and formalize - a more useful measurement system to gauge the overall maturity of state wind markets. To this end, the revised long-term goal will be "By 2010, at least 30 states will have mature markets that can support wind's continued growth." This will be a more robust goal, as it will gauge markets in terms of major indicators such as overall awareness, legislative and regulatory environment and resource assessment in addition to installed capacity and wind resource potential.

5.2.2 Technical Challenges

Numerous institutional and informational barriers have slowed, and continue to slow, the adoption of wind power. These barriers are distinct from technology cost and performance issues yet, ultimately, could prove to be just as important. For example, some states have aggressively adopted policies and undertaken other barrier reduction actions to facilitate the deployment of wind energy. Other states have not yet explored their wind resources or the potential for wind to stimulate economic activity. The challenge for Technology Acceptance is to develop, disseminate, and support an appropriate mix of technical information for - and general outreach to - a reasonable number of states where there are strong wind resources yet little public or private wind momentum exists. Another challenge is to bring the wind message to potential users of distributed wind technology. By reaching out to farmers, ranchers, Native Americans, and other state and local stakeholders, WPA can help build a state-level coalition. By building bridges to environmental and regulatory communities, the NWCC can help reduce barriers of interest at the national level.

The Wind Program's Technology Acceptance efforts complement those being pursued under other elements of the Wind Program including the Systems Integration subkey activity, as both are aimed at reducing undue barriers to use of wind power. The Systems Integration work targets the more technical barriers, while the Technology Acceptance efforts tend to address issues associated with state, local and consumer-owned utility unfamiliarity with the technology.

5.2.3 Technical Approach

Strategy

The strategy of the Technology Acceptance effort is to build, in all applicable regions of the country, state-level support for the increase use of wind power. A state-focused strategy acknowledges the critical role that states have played, through policy-making, incentive adoption, and stakeholder involvement, in wind power's development to date. The primary mechanisms for pursuing this subkey activity are the Wind Powering America (WPA) program and the National Wind Coordinating Committee (NWCC).

WPA was established in 1999 to identify barriers to wind power's use and to pursue strategies for overcoming them, primarily at the state level. The WPA team has developed a package of technical assistance and outreach activities that is aimed at key user communities – farmers and ranchers, Native Americans, rural electric cooperatives and consumer-owned utilities, and publicly-owned facilities. DOE's Regional Offices work with these stakeholders and state and local officials to identify interest in wind power, identify their needs, and form state level Wind Working Groups to build the local presence required to accelerate wind's widespread adoption. WPA has adopted a number of operating principles, including: focusing work where there are good wind resources yet little to no development, or working at the "market margins"; leveraging and building institutional partnerships; developing innovative pilot applications; replicating successes; utilizing existing national, regional, and local expertise; and coordinating with established wind institutional resources.

The strategy of the NWCC, a U.S. consensus-based collaborative formed in 1994, is to establish dialogue among key stakeholders, and catalyze appropriate activities to support the development of environmentally, economically, and politically sustainable commercial markets for wind power. NWCC members include representatives from electric utilities and support organizations, state legislatures, state utility commissions, consumer advocacy offices, wind equipment suppliers and developers, green power marketers, environmental organizations, agriculture and economic development organizations, and state and federal agencies. The Wind Program provides the largest share of financial support for the NWCC but does not determine its research and outreach agenda.

Performance Measures

Since the initiation of the Wind Powering America program, three phases of wind acceptance have been used to measure progress, based primarily on a state's installed capacity (<20 MW, 20-100 MW, >100 MW). Because it is recognized that several variables in addition to installed capacity contribute to overall maturity of state wind markets and that there are emerging markets for wind power, the Wind Program is re-evaluating measures of success. Generally, however, Technology Acceptance will continue to be measured in three phases. The first phase is characterized as being the time before significant levels of awareness or adoption are evident in a given state. The second phase is the time between when WPA-supported activities have begun in a state and when the state-based efforts become relatively self-sufficient. This phase is generally characterized by intense Technology Acceptance efforts and support and by an increasingly active wind market. When the final phase is reached, and mature markets conducive to wind are established, Technology Acceptance activities can frequently wind down, and focus can be shifted to other states. At that point, in-state expertise has reached a level sufficient to continue the momentum built by DOE's Technology Acceptance activities. WPA's experience suggests that this level corresponds roughly to the time that the installed capacity reaches the 100 MW level. However, there may be strategic considerations under which activities in a state might continue well past the 100 MW level.

Current State Progress Measurement System

Table 6 lists the annual target levels that have been used to measure Technology Acceptance progress since the initiation of the Wind Powering America Program.

Table 6. Technology Acceptance Goal and Annual Targets

Year	Number of States With Mature Wind Markets (Technology Acceptance Goal)	Number of States With Active Wind Markets (Supporting Targets)
2002	8	13
2003	10	19
2004	12	25
2005	16	32 (interim target)
2006	19	34
2007	22	36
2008	25	38
2009	27	39
2010	30 (goal)	40

Figure 15 illustrates in general how Technology Acceptance goals are tracked and how areas of emphasis are identified on a state-by-state basis. The figure also shows the role of the Technology Acceptance Steering Committee, which provides overall strategic guidance to the effort and has provided general input in defining a state's level of momentum. The membership of the Steering Committee is drawn from a range of sectors and experts and includes DOE program and field management.

The top portion of the figure shows which states are in which wind momentum category (as of the end of 2004). The map also identifies which states have been part of Technology Acceptance activities to-date and which await future activity. The bottom portion of the figure illustrates how the Program tracks activities, provides a projection of when targets will be met, and identifies expected future activities. This information is used to support program performance reporting requirements and to identify future priority program activities. The program maintains a state activity tracking database on the WPA website to provide detailed information about activities and to assist the program and the WPA Steering Committee in its planning function.

For FY 2005, the program will develop a more detailed and rational process to assist in resource decision making across Technology Acceptance. This process will build on existing efforts and new tools available to the program, including a new WPA consolidated monthly activity reporting system. The program will revise its performance indi-

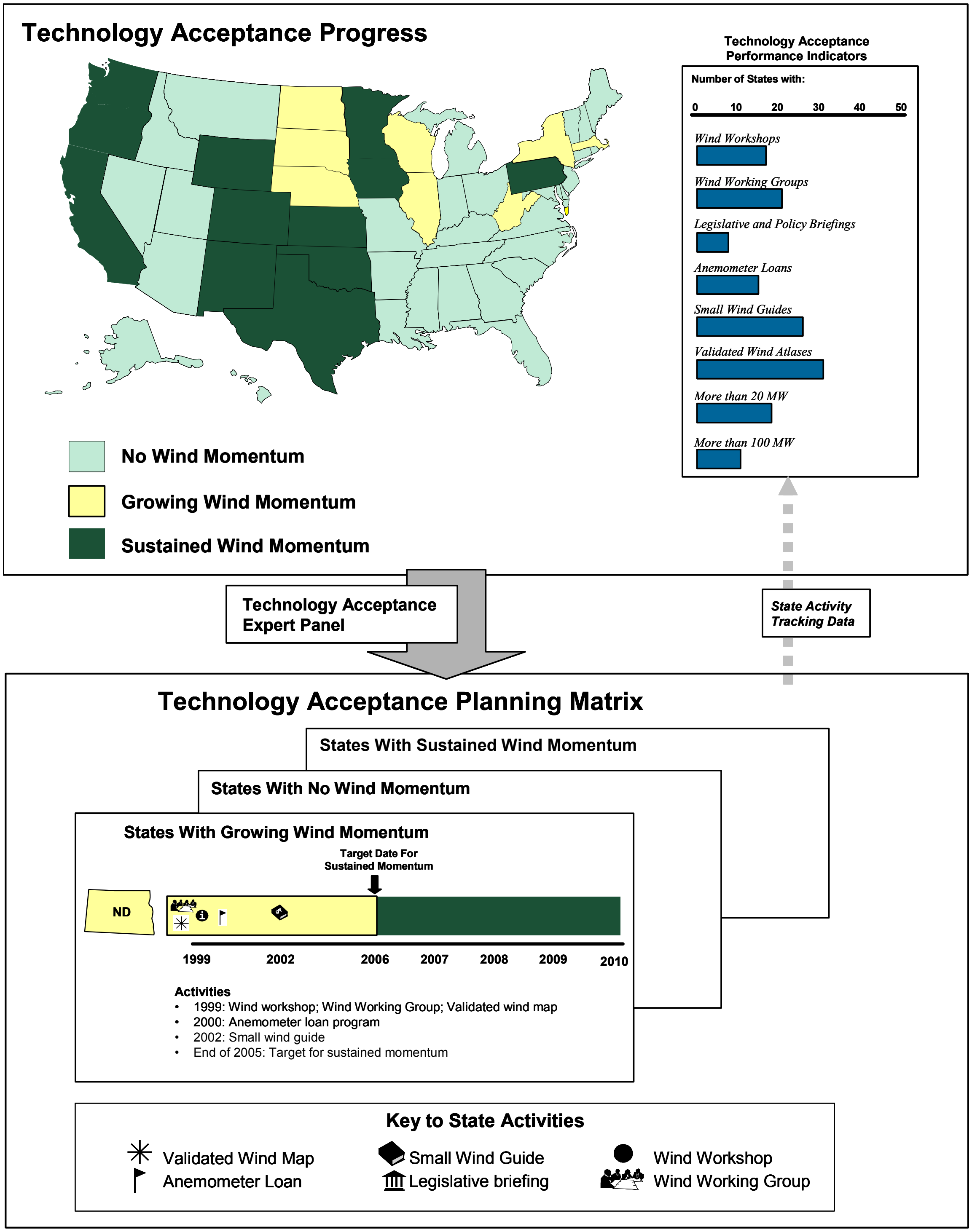


Figure 15. Status of Technology Acceptance Activities (end of FY2003) and Illustration of Planning Approach for Future State-Level Activities

cators and measure the progress in each state where work is underway and identify candidates to receive future program assistance. The overall indicator will be level of state maturity related to wind acceptance, which will be determined in conjunction with appropriate DOE headquarters and field program managers and the WPA Steering Committee.

As the Technology Acceptance effort achieves its goals, and produces the desired mature markets and sustained momentum, the Wind Program anticipates that the focus of Technology Acceptance will change. For example, the need for resource maps and anemometer loans will end as momentum builds. In addition, new markets are and will continue to emerge where wind technology, particularly new low wind speed turbines, will play a role. The program expects that Technology Acceptance efforts will transition from state-based technical assistance to a more-regional focus on emerging markets. As this change occurs, the programmatic distinction between Systems Integration and Technology Acceptance will be reduced, and overlapping functions will be eliminated.

5.2.4 Research Activities

The Program is pursuing six themes under the Technology Acceptance subkey activity.

Outreach to State-Based Organizations

Over the past several years, the program has worked to foster the formation of state wind working groups to serve as focal points and local presence for outreach to local communities and stakeholders. As of the end of FY2004, formal groups had been established in 22 states across the U.S., from Virginia to Hawaii. Some of these have become quite self-sufficient and Technology Acceptance support for them has been reduced. However, the majority of states still do not have functioning groups.

Through these state groups, a mix of WPA-supported technical and general activities is provided. For example, understanding the wind resource is the first step of many toward increasing installed wind capacity. WPA has found that many state, county and local stakeholders are unaware of their wind resources or are using information developed almost 20 years ago. To begin to address this information deficit, WPA launched an anemometer loan program with states to begin to increase familiarity with wind energy, in general, and to create the intellectual infrastructure necessary to move forward. Similarly, WPA began to cost-share development of updated state wind resource maps that show public and private officials, as well as landowners and other stakeholders, the extent of the wind resource in their state. At the end of 2004, there were 31 validated state wind resource maps. By the end of FY2005, validated maps will be available for Missouri, Nebraska, and western areas of Alaska.

Wind provides substantial rural economic development opportunity because of the significant overlap of wind resource and rural areas. WPA directly engages state-based agricultural organizations, as natural partners for rural wind development, to leverage pre-existing contacts with the farming and ranching communities. Currently, wind farms in rural areas provide annual payments to the landowners, added state and local tax revenues, local revenues during construction, and quality long-term jobs. The NWCC has directed a part of its recent efforts at developing techniques for estimating the local economic benefits of rural wind development, and has applied that work to three case studies. Over the next several years, the NWCC intends to work with local elected officials and economic development staff to educate them on how they can estimate wind power's benefits to their local community. The NWCC has also played an important role in developing a better understanding of the transmission and distribution system infrastructure required to support rural wind development. This effort is coordinated with, and complements, the Systems Integration activities to engage the regulatory community on wind issues.

WPA has established partnerships with national, state and local agriculture sector interests. A number of these, such as the American Corn Growers Association and the Cattlemen's Association, have joined to form the Agriculture-Wind Interest Group. WPA also works with the U.S. Department of Agriculture and others to take advantage of their extensive contacts with stakeholders in the rural community and to increase access to USDA's rural power systems funding programs. In February 2003, the Wind Program, on behalf of DOE and EERE, began a cooperative effort to support USDA's implementation of the Farm Security and Rural Investment Act of 2002 ("the Farm Bill"), through a five-year program to foster the greater use of renewables in rural communities.

WPA, in conjunction with the National Conference of State Legislatures, has provided legislative briefings on technical aspects of wind energy systems. The NWCC has an on-going wind farm siting work group that is detailing best practices for permitting wind generation facilities. An early NWCC focus on avian issues has played an important role in moving that debate toward having a factually and methodologically sound basis.

Small Wind

The Technology Acceptance effort works to remove barriers to the increased use of distributed and/or small wind technology, in support of the program's Technology Viability efforts on DWT. The small wind outreach efforts provide important non-technical support to the industry's small wind roadmap, as described in the DWT chapter. Technology Acceptance activities to overcome the barriers to the use of small wind systems include focused small wind energy workshops and meetings, development of a small wind calculator, customized wind resources maps, and development of state-specific Small Wind Guides containing resource, policy, technical information, and state contacts. As the technology development efforts under the Wind Program's DWT subkey activity lead to more cost-effective small wind turbines, the small wind outreach efforts may grow in importance.

Institution Building Through Utility Partnerships

The Technology Acceptance effort has established partnerships with public power organizations such as the American Public Power Association (APPA) and with rural cooperatives associated with the National Rural Electric Cooperative Association (NRECA). At the present time, the sharing of experience among the members of this community has helped build momentum for utility acceptance, and even support, for wind. For example, NRECA has sponsored workshops in Kansas, Colorado, and North Dakota to facilitate discussion, and Basin Electric Power Cooperative, with its pioneering support for 80 MW of wind in South Dakota and North Dakota, has become an important spokesman for the technology. The Technology Acceptance efforts coordinate closely with, and take advantage of, Utility Wind Interest Group (UWIG) activities under the Systems Integration subkey activity. In the longer-term, the outreach and communication partnerships with utilities will prove to be an important element of program support to regional groups fostering greater integration of wind power.

Support for Native American Interest in Wind Power

There are no large-scale wind developments on Native American lands, despite the wide availability of excellent wind resources on those lands. A milestone was achieved, however, in early 2003 when the first Native American 750-kilowatt (kW) wind turbine was installed on the Rosebud Sioux Indian Reservation.

Technical assistance and outreach efforts are underway with over 20 tribes from 13 states and regions with good wind resources to expand Tribal wind activities, from planning and resource assessment to project development options. For example, WPA helped establish a Native American Wind Interest Group (NAWIG) which facilitates encourages Tribal experts to engage other interested Tribal representatives on all aspects of wind energy. WPA also administers a Native American anemometer loan program that is enhanced with focused technical assistance to help Tribes understand their wind resource and potential development options. WPA has also provided guidance to Tribal officials seeking financial awards for wind exploration and business plans, and provides a means for Native Americans to attend wind energy training programs under the DOE-supported WEATS (Wind Energy Applications and Training Symposium) program. The wind program also works with other elements within EERE, such as DOE's Tribal Energy Program, to increase the use of wind power on Tribal lands. WPA also engages numerous Tribal organizations such as the Intertribal Energy Network (ITEN) to augment existing activities.

Environmental Considerations

Wind energy is a net environmental benefit to the communities in which it operates and to the nation overall: it emits no air pollution or greenhouse gases, reduces dependence on imported sources of energy, contributes to local economic development, and does not present a security threat. However, the construction and operation of wind turbines can create real impacts on a range of environmental resources. Some of those impacts are common to all major construction projects, specifically those which impact air, soil, and water quality. With appropriate use of accepted best management practices, these can be minimized or avoided.

In addition, there are significant potential impacts that result from characteristics of wind facilities themselves. These are the areas which drive the Wind Program's environmental strategy and include impacts on ecological resources, noise levels and visual aesthetics. Wind development has the potential to significantly reduce, fragment or degrade habitat for wildlife, fish and plants, as well as to directly and indirectly cause harm to biotic communities, especially to birds and bats. The wind program has led substantial research efforts to understand, avoid and minimize these impacts, and will continue to do so. Noise impacts result from construction, turbine operations, substation operations (transformer noise and switchgear noise), and transmission line noise. Proper siting and equipment design and the use of setbacks from residential areas can help minimize these impacts. Finally, while the visual impact of wind turbines on the landscape is quite subjective, it poses a real challenge to the continued growth of wind energy. As with noise and ecological impacts, visual aesthetics must be considered in the context of other types of development that affect the visual landscape.

Recognizing the net environmental benefit of wind development but also the potential for environmental impact, the Program will pursue strategies to meet several environmental objectives for wind energy. These objectives include: identifying and supporting scientific research priorities relating to the impact of wind energy facilities on wildlife, assisting other federal agencies in developing and supporting mechanisms that enable developers to meet the statutory, regulatory, and administrative requirements that protect wildlife, helping to ensure that responsible environmental compliance can be achieved by wind power developers without disadvantaging the economic outlook for wind growth, and addressing sources of consumer resistance to large scale deployment of wind, particularly visual and auditory.

Emerging Applications

A portion of future Technology Acceptance efforts will be focused on bringing new applications for wind to the attention of key stakeholder groups. This Technology Application theme is a result of growing awareness of the role that low-cost electricity and/or mechanical power can have in markets other than the bulk power market that has been the program's traditional target application. Potential new applications include the use of wind to provide clean water, meet clean air requirements, comply with federal clean power requirements, develop renewable energy on public lands, and to produce hydrogen for transportation and electric generation markets.

Wind energy can be used to power the production or movement of clean water (desalination) and facilitate water management strategies for operators of hydropower facilities. Wind turbines may also be designed and tailored to serve in various agricultural, mining, or water pumping applications. WPA and the NWCC are both expected to be increasingly important as the deployment of wind turbines offshore advances, and as added communications and information dissemination requirements arise. The use of wind power to meet local economic, educational or environmental benefits is increasing. This is seen through community-based projects such as installing single turbines on public school grounds. It is also demonstrated through employing renewable energy technology to meet State Implementation Plans for air quality, as described in EPA's August 2004 published guidance.

Since the federal government is the largest user of energy in the world, its use of wind power can play an important role in expanding early wind markets. Federal facilities are beginning to look to wind as a source of clean power. In general, however, the federal facilities are not the actual owners of the wind plants, but have agreed to purchase power from those plants. The Technology Acceptance activity will continue to work with the Federal Energy Management Program (FEMP) to foster use of wind power by federal agencies.

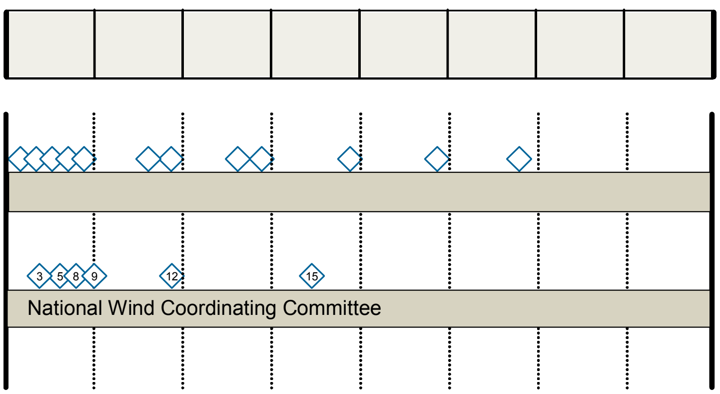
An important success, related to public lands, was achieved in 2003 when the Bureau of Land Management (BLM) adopted procedures that include wind in BLM's long-term land plans and allow Programmatic Environmental Impact Statements (PEIS) to streamline siting processes. These changes, advocated by the wind program and officially supported via technical assistance and funding, should greatly facilitate the use of wind power on federal lands. This effort will also serve as a model for other federal agencies such as the U.S. Forest Service and USDA and state public lands administrators.

Finally, there will likely be a strong role for wind technology, among others, in securing the future hydrogen economy. The electricity produced by wind turbines (either dedicated wind turbines or using surplus power) could be the lowest-cost renewable resource to create hydrogen through electrolysis of water. Wind-produced hydrogen could then be stored, shipped and used for either electricity generation or as a transportation fuel in fuel-cell powered vehicles.

5.2.5 Milestones

Milestones for the Technology Acceptance subkey activity provide planning guidance and a means by which progress can be tracked.

Technology Acceptance



(WWG) summit

5. Facilitate Midwest Wind Transmission Meeting
6. 32 states with greater than 20 MW, 16 states with greater than 100 MW
7. 35 validated state wind resource maps
8. Facilitate Siting/Permitting Workshop
9. Partner with USFWS on Regional Meetings
10. 34 states with greater than 20 MW, 19 states with greater than 100 MW
11. 25 Wind Working Groups, 15 of which have announcements and information posted on websites
12. Update Methods and Metrics document
13. 36 states with greater than 20 MW, 22 states with greater than 100 MW
14. 30 Wind Working Groups, 25 of which have announcements and information posted on websites
15. Transmission investment study
16. 38 states with greater than 20 MW, 25 states with greater than 100 MW
17. 39 states with greater than 20 MW, 27 states with greater than 100 MW

6.3 Supporting Engineering and Analysis

The Supporting Engineering and Analysis (SE&A) subkey activity provides a number of necessary functions to support industry and the program and to further wind energy technology deployment and application.

6.3.1 Goal

The efforts under this subkey activity are expected to help reach all four of the Wind Program's goals.

6.3.2 Technical Challenges

The stakeholder community's perception of the credibility of the Wind Program's efforts is important. The challenge is to establish processes, procedures, and analyses that enhance this credibility. Each of the activities under the SE&A activity presents its own set of unique challenges.

6.3.3 Technical Approach

Strategy

The strategy of the SE&A effort is to undertake, in consultation with industry, critical cross-cutting activities that span the needs of the wind stakeholder community, but are unlikely to be supported by individual companies.

Performance Measures

The success of this subkey activity, and progress in meeting its objectives, will be reflected in the progress made toward the four wind program goals. The relative contributions and performance metrics can readily be quantified by the number of publications produced; the number of public/private collaborations initiated; and the efficiency and effectiveness of program operations. The achievement of the milestones provided below will also provide an indication of success.

6.3.4 Research Activities

The Wind Program is pursuing two specific research areas under the Supporting Engineering and Analysis subkey activity:

Supporting Technical Analyses and Communication Products

Technology Planning & Analysis: NREL and its subcontractors will provide technology planning and analytical expertise to program headquarters to support strategy formulation, technology road mapping, program planning, and the development of program metrics and benefits analyses. This will help DOE meet expectations and requirements for the effective R&D program management necessary to reach program goals. It will also enhance the management link with DOE headquarters, laboratory implementation of the annual operating plan, and support of the annual program planning and review process. Technical assessments will monitor the status of current wind technology in diverse applications, assess future improvements in the cost performance of wind technology (e.g., technology characterization), assess benefits in support of the Government Performance and Results Act (GPRA), track installed U.S. wind capacity and industry/utility plans for expansion, and identify technological pathways that will lead to wind's success in the marketplace. Analysis will also supplement program activities focused on large and small wind systems, systems integration, market opportunities, hybrid systems, and emerging wind applications.

These analyses will provide a basis for prioritizing wind energy technology R&D alternatives, establish program goals and metrics to measure program progress, and ensure that research activities can be demonstrated to have a direct link to achieving the program's top-level objectives and goals. A formal performance measurement system and technology tracking process will be implemented to guide multiyear planning and to realize the benefits of performance-based management. This project will also support collaborative R&D activities associated with the IEA Wind Implementing Agreement, including participation in the IEA Wind R&D Executive Committee and coordination with Annexes and other implementing agreements.

Communications Support: This project supports and facilitates communication of Wind Program goals, activities and research highlights. The program publishes and distributes communication products to appropriate audiences including government officials, researchers, members of the wind energy industry, utility engineers and planners, and other stakeholders interested in the Wind Program and the research conducted by the NWTC. The communications effort will coordinate the production and publication of technical papers, outreach brochures and materials, journal articles, web sites, and conference papers and exhibits.

DOE will co-sponsor conferences that provide a cost-effective forum for the presentation, discussion, dissemination of wind energy research and development achievements, and cost-effective marketplace applications. The target audience to be reached in such meetings will include representatives of state and local governments, researchers, utilities, independent power producers, project developers, manufacturers, consumers, and representatives of various federal agencies.

NWTC Operations and Program Management

The SE&A effort also supports the management of the program and the management and operation of the National Wind Technology Center (NWTC). The NREL/SNL program management team leads and manages over $34 million of complex and diverse Wind Program activities that are broken down into distinct tasks to assure appropriate high-level management focus for work that is performed at DOE's two principal National Laboratories for wind energy research.

NWTC Operations: The NWTC facility is located on a 280-acre tract of land in northwestern Jefferson County, Colorado. The NWTC oversees operation of 32 facilities (e.g. test laboratories, field test sites, and buildings including the Industrial User Facility), and over 150 components (e.g. industry prototype turbines, research turbines, meteorological towers, test sheds). Operations activities will define and develop site infrastructure and schedule shared NWTC resources. The NWTC offers a uniquely ideal environment for testing and evaluating wind turbine designs. Winds from the west have been influenced by complex mountainous terrain, while those arriving from the east represent conditions more typical of the Great Plains. Instrumentation is optimized to measure and document the wind characteristics associated with these two flow patterns. The measurements serve as planning aids for experiments and turbine evaluations, and as sources of current and climatological information. This project will continue continuous data collection from the West Meteorological (M2) Tower and operate the onsite and Web current weather displays. The NWTC will prepare monthly summaries of the wind conditions and validate the raw collected data and archive. This operation is being migrated to an external subcontractor and the NREL/SRRL group to acquire, store and post the data. The external subcontractor will also maintain other site meteorological towers.

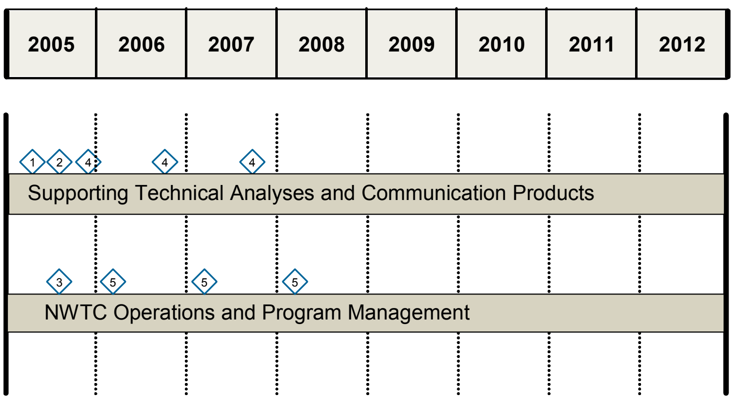
Program Management: The NREL/SNL program management team will lead and manage over $29 million of Wind Program activities that are broken down into distinct tasks to assure appropriate high-level management focus for work that is performed at DOE's two principal National Laboratories for wind energy research. This work, combined with the over 80 subcontracts administered for the Wind Program, presents a significant management challenge. The Program Management effort provides direct technology management support to the DOE Wind and Hydropower Technologies Program headquarters in Washington, DC, including strategic planning, monitoring, and day-to-day management of work performed with program funds by Laboratory staff and subcontractors, and representing the program within NREL, within the National Laboratory System, to DOE and to the US wind industry. This effort supports DOE's management approach to strategic program planning and execution in two key areas: 1) ongoing Technical Assessment to monitor the current status of wind technology, evaluate that status within the context of the needs of the marketplace, and identify technological pathways that will lead to wind energy's successful competition in the marketplace; and 2) a formal Peer Review and Stakeholder Input process to benefit from the guidance of industry and the research community and to provide an outside view of the program. The program's planning framework supports DOE/Laboratory program management team decisions about strategic program directions and funding priorities.

Ocean energy has features in common with wind energy. As the wind program begins R&D on offshore wind power, the potential for ocean wave, current and tidal power can be assessed for a small additional investment. This Ocean Energy Assessment project is to perform a preliminary evaluation of Ocean Energy Systems for the US. The technology status of wave, current and tidal power will be evaluated, the potential for energy production from ocean energy systems will be estimated, and the permitting requirements and environmental effects will be assessed along with similar studies for offshore wind energy systems.

6.3.5 Milestones

Milestones for the Systems Engineering and Analysis subkey activity provide planning guidance and a means by which progress can be tracked.

Supporting Engineering and Analysis



Milestones

1. Join IEA – Ocean Energy Systems Implementing Agreement
2. Complete 2004 Peer and Stakeholder Review Report
3. NWTC safety inspection
4. Publish Wind Power Today
5. MYPP update

Appendix A: Wind Research Portfolio Evaluation

At the core of the strategic planning framework is a Wind Technology Pathways Model. That model is shown in Figure A-1. *{It is important to note that all numerical values in this discussion are illustrative, and are provided simply as a way to guide development of the model's structure. Similarly, the list of technology improvement opportunities are also tentative and subject to change.}*

An important objective of the pathways model is to demonstrate that there are sufficient opportunities for wind technology to be improved, through program-sponsored R&D, such that the goals of the program can, in fact, be achieved. A second objective of the pathways model is to explore the implications on program success in meeting goals if a particular research project does not yield the expected technology improvement benefits. Although Figure A-1 may give the impression that the analysis framework is static and deterministic, the model treats the problem probabilistically to account for uncertainties in the outcomes of R&D.

Looking at the three portions of Figure A-1, starting at the top, in more detail:

Technology Improvement Opportunities

The program research staff has identified a set of technological improvements that are expected to contribute to the technology's becoming more cost effective. These have been termed the *Technology Improvement Opportunities (TIO).* Wind turbine design is a matter of constant tradeoff between the competing demands of lower cost, greater energy productivity, increased lifetime and durability, and maintenance cost. Achieving greater energy production may cost more, or it may cost less. Reducing materials to reduce capital investment may adversely affect O&M costs. These are the designers' tradeoffs, and they are captured in the model.

Total System Analysis

To illustrate how the model works in its simplest form, assume that there are only two TIOs. The first reduces capital cost by 10% and also increases energy production by 5%. The second, which is totally independent of the first, reduces cost by another 7%, but produces 4% less energy (a cost-effective trade-off). Simply adding the two together gives the outcome that cost is reduced by 17% and energy production is increased by 1%. Because cost of energy is proportional to capital cost and inversely proportional to energy production, the COE reduction from these two TIOs would be (1-0.17)/(1+0.01), or 17.8%.

However, as can be seen from Figure A-1, the outcomes of each TIO category (capital cost, energy production, and O&M) can be represented in the model by a range. Using a range of values is appropriate due to the inherent uncertainties about levels of success of R&D activities. In fact, the model actually represents this range as a probability distribution around a most likely value. The model generally uses a triangular distribution, such that the end points of the bars in Figure A-1 represent values with essentially no likelihood of occurring. The model can account for any potential interactions among the different TIOs.

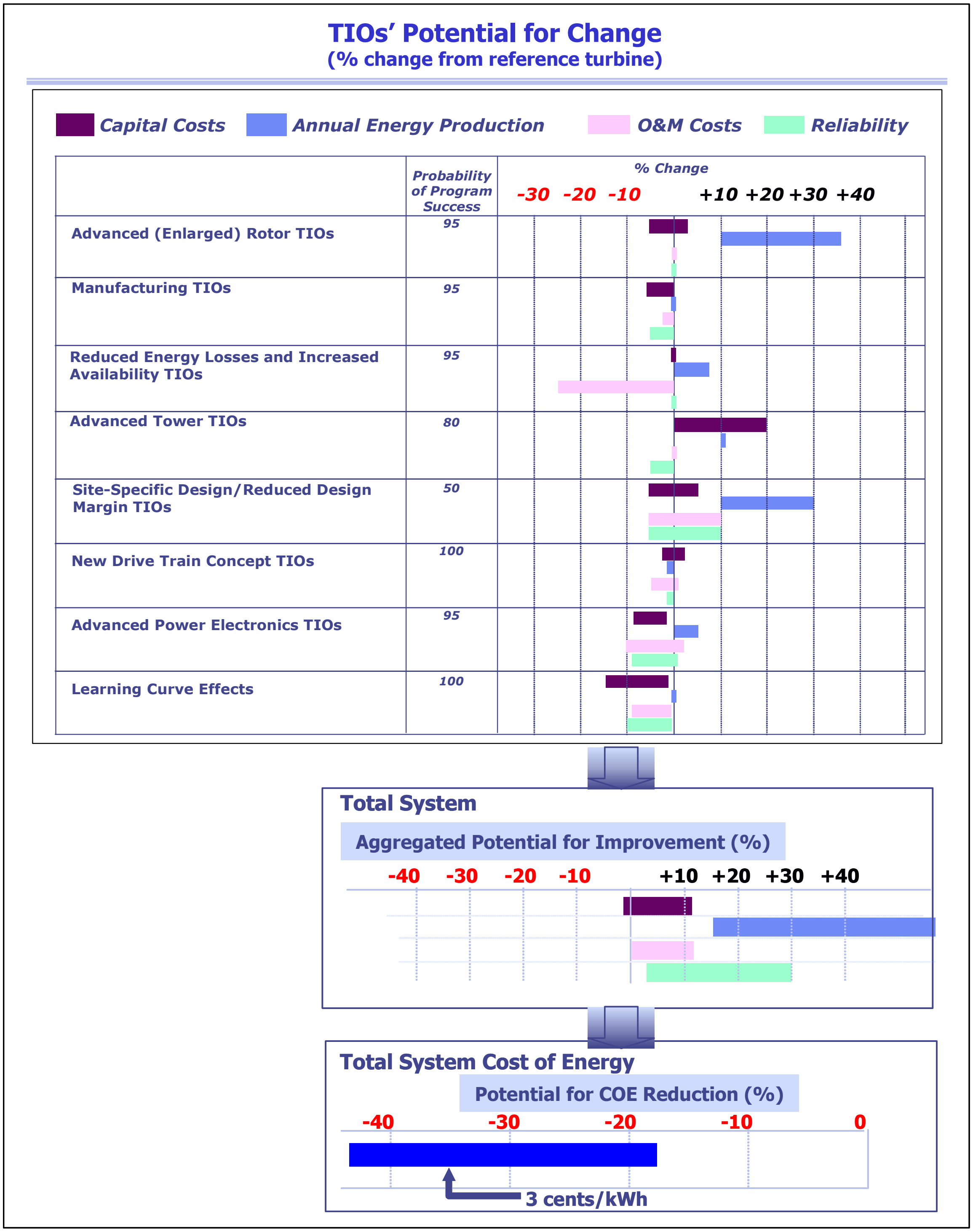


Figure A-1. Wind Technology Pathways Model

In contrast to the simple example just discussed, the model adds the potential changes probabilistically, and produces a range of potential outcomes for cost, energy production, and O&M. This probabilistic treatment is illustrated in Figure A-2.

The model further accounts for the variety of technology configurations that might be used to achieve progress (e.g., through different gearbox designs). The model's ability to analyze the variety of approaches to meeting goals is what makes it a true "pathways" model. To illustrate, all turbines require a tower and rotor; but different tower designs could be married to different rotor designs, and still achieve the same level of cost-effectiveness. These combinations can be thought of as competing pathways. It is critical that the program be able to represent the fact that there are many potential approaches to meeting goals, that some are riskier than others, and that some might potentially yield a higher level of improvement in exchange for that additional technological risk.

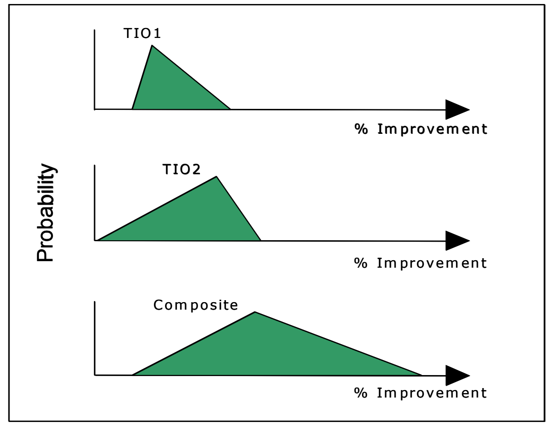


Figure A-2. Probabilistic Treatment of TIOs

Cost of Energy

The model uses a cash flow-based financial representation to calculate a levelized cost of energy (COE). The percentage changes in capital cost, energy production, and O&M are applied to the baseline COE to calculate the changes in COE due to program activities. In addition to the distribution of COE outcomes, the model also produces an estimate of the most likely value and provides a curve of COE versus probability of occurrence.

Assessment of Annual Progress

The Wind Technology Pathways Model also serves as the program's tool for quantifying annual progress in R&D. The program accomplishes that annual assessment through a process called the A*nnual Turbine Technology Update (ATTU)*. The progress measured by the ATTU is the combined result of research conducted under the LWST subkey activity and of those SR&T research activities that support the LWST public/private partnerships.

Section 5.1 describes the ATTU process in greater detail, with Figure 11 providing the results of the assessments for FY 2003 and FY 2004.

Research Activity Prioritization

An important objective of the wind research evaluation process is to demonstrate that every research activity undertaken contributes in a meaningful way to the achievement of program goals. It is neither practicable, nor desirable, to try to quantify this linkage at the subtask level. It is, however, quite informative to make the linkage in a qualitative way, as a tool for forcing a constant questioning of the relevance of the subtask effort to overall program goals and objectives.

The program makes that qualitative linkage as shown in Figure A-3. As seen in the figure, every program subtask is assessed for its contribution to the various TIOs. As illustrated, some subtasks may be highly relevant to several TIOs, others to only one TIO, and yet others, when examined within this framework, may prove to have little relevance to any. As the program prioritizes and focuses its research portfolio, those subtasks that can apparently make only minimal contribution to technology improvement will be terminated. This process of annual re-examination of program subtasks also provides a means by which activities that have achieved most of their initial objective, i.e., have contributed to the TIOs to the extent possible, can be identified and terminated. The definition of these off-ramps is a critical element of the program's management strategy. In Figure A-3, subcontract 6 is an example of an effort that is no longer contributing to the program goals.

Impact: High H; Moderate M; Low

Technology Improvement Opportunities (TIOs)		LWST & DWT Subcontracts: Subcontract 1	Subcontract 2	Subcontract 3	Subcontract 4	Subcontract 5	Subcontract 6	SR&T Research Tasks: Research Activity 1	Research Activity 2	Research Activity 3	Research Activity 4
Advanced (Enlarged) Rotor	Advanced materials	M						H			
	Changed/improved structural/aero design	H						M	H	H	M
	Active controls	M	M					H	H		M
	Passive controls		M					H	H		M
	Higher tip speed ratios/lower acoustics		H					M	H	H	M
Manufacturing	Manufacturing methods	H									
	Lower margins	M									
	Manufacturing markups										
Reduced Energy Losses & Increased Availability	Health monitoring (SCADA, etc)										
	Blade soiling mitigation										
	Extended scheduled maintenance										
Advanced Tower TIOs	New Materials	H									
	Innovative structures	H							M	M	
	Advanced foundations	H							M	M	
	Self-erecting designs	H							M	M	
Site-Specific Design / Design Margin Reduction	Improved definition of site characteristics										
	Design load tailoring								H	H	
	Micrositing								H	H	
	Favorable wind speed distributions and shear								H	H	
Drive Train Concepts	Permanent magnet generator	H		M	H						
	Innovative mechanical drives	M	H	H	M M						
Advanced Power Electronics TIOs	Incorporation of improved PE components	H		M	H	H					
	Advanced circuit topology					H					
Learning Curve Effects		M	H	H	M						

Figure A-3. Assessment of Program Activity Contribution to TIO Progress

Summary

In summary, the wind program has established a program research portfolio evaluation process that:

- Sets program COE goals based on a careful analysis of opportunities for technology improvement through program-sponsored R&D
- Tracks progress toward those goals using the same analysis tools as are used for setting goals, and reports that progress annually in terms of cost of energy
- Provides program funding guidance on activities that may no longer be contributing, or have the potential to contribute to, technology progress
- Ensures that all program-sponsored subtasks can be shown to contribute to achieving program targets for cost reduction, energy production enhancement, or O&M cost reduction.